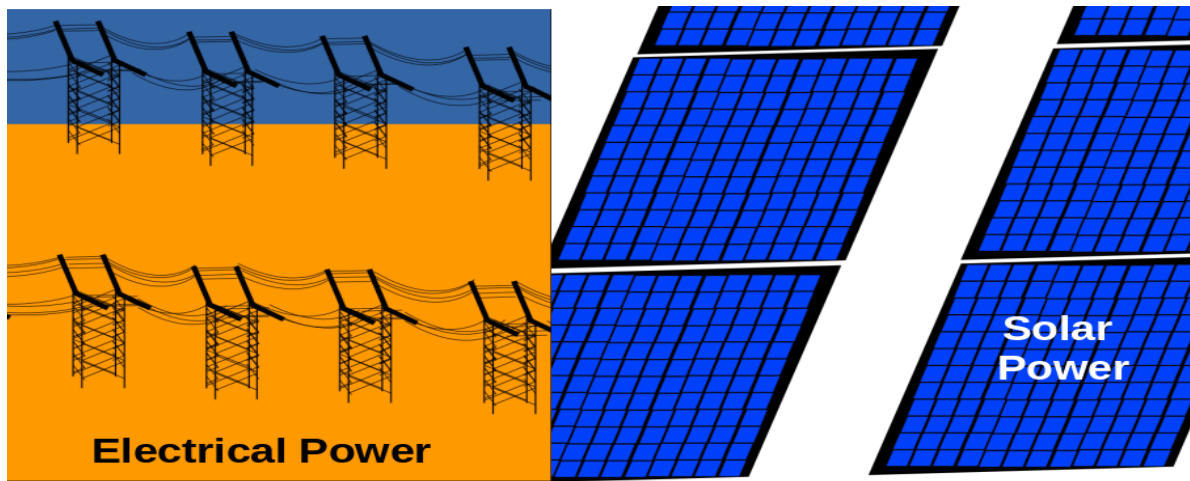




## **Energy Infrastructure Transitions: Photo Voltaic Industries**

**By Joseph Matthew Wendland**

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# **Energy Infrastructure Transitions: Photo Voltaic Industries**

**How biases, glitches, and  
misunderstandings cause market opportunities**

**Joe Wendland**

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## **ELECTRICAL INDUSTRY: CARBON INEFFICIENCIES**

### **Chapter Summary**

This chapter considers a major source of inefficiency in our system. Carbon is an externalities and a cost which is currently not priced into our economic system. As a source of inefficiency, various options are considered to fix the inefficiency.

#### **Carbon the Externalities**

An issue facing the energy industry is the issue of carbon emissions. The issue of carbon emissions has implications for both international relations, environmental quality, and future economic growth. In order to understand the issue of carbon, it is necessary to understand how our economic system evaluates energy projects. The example employed here will be an analogy of our economic system as a scale. Here the scale is used to measure and evaluate various energy projects. Through a study of the scale and its application to energy industry, we can gain an understanding of the carbon issue.

Our economic system is like a scale used to measure the value of business opportunity. A scale has two sides to its balance. The equivalent economic measures include cost and revenue. Each side can hold a weight. The weights are like the amount of cost or revenue. The scale's balance can tilt either way, indicating to the user which weight is greater. In the same way, company situation can indicate either profit or losses, tilting the business into growth or bankruptcy. As our economy goes about evaluating energy projects, the scale of our economy evaluate determines which projects to create.

The diagrams below shows a scale. These scales demonstrate the analogy of how the economy works. This framework considers the lowest cost source of energy as the best source of energy. The fuel which tips up on the scale is the best and cheapest source of energy.

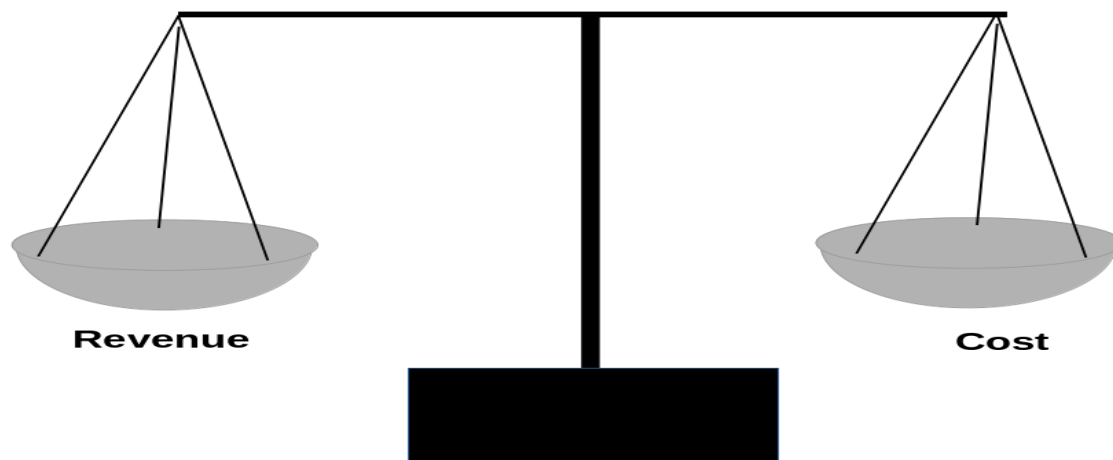


**Figure 1**

The profit equation determines how profitable a project or a firm is. It has two components. The first component is revenue. The second component is cost. Profit is the total of revenue less costs. The revenue component is the product of price and volume. It reflects the amount of value our society applies to the company's output. The cost component is a sum of all the project's costs. The price related to revenue reflects a measure of our society's evaluation of product value. The volume component indicates how many products to count. The cost component reflects a measure of the resources used by the firm to employ its production. The net gain to our economy's resources is the net of resources products (revenue) and resources consumed (cost).

$$\text{Profit} = \text{Revenue} - \text{Cost}$$

$$\text{Revenue} = \text{Price} \times \text{Volume}$$

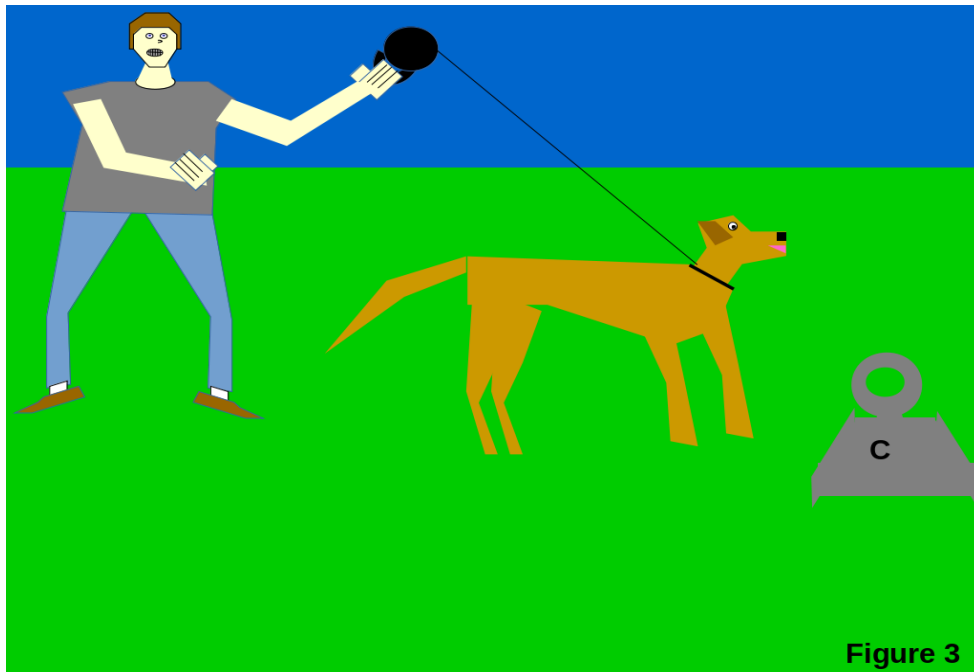
$$\text{Cost} = \sum \text{individual costs}$$

**Figure 2**

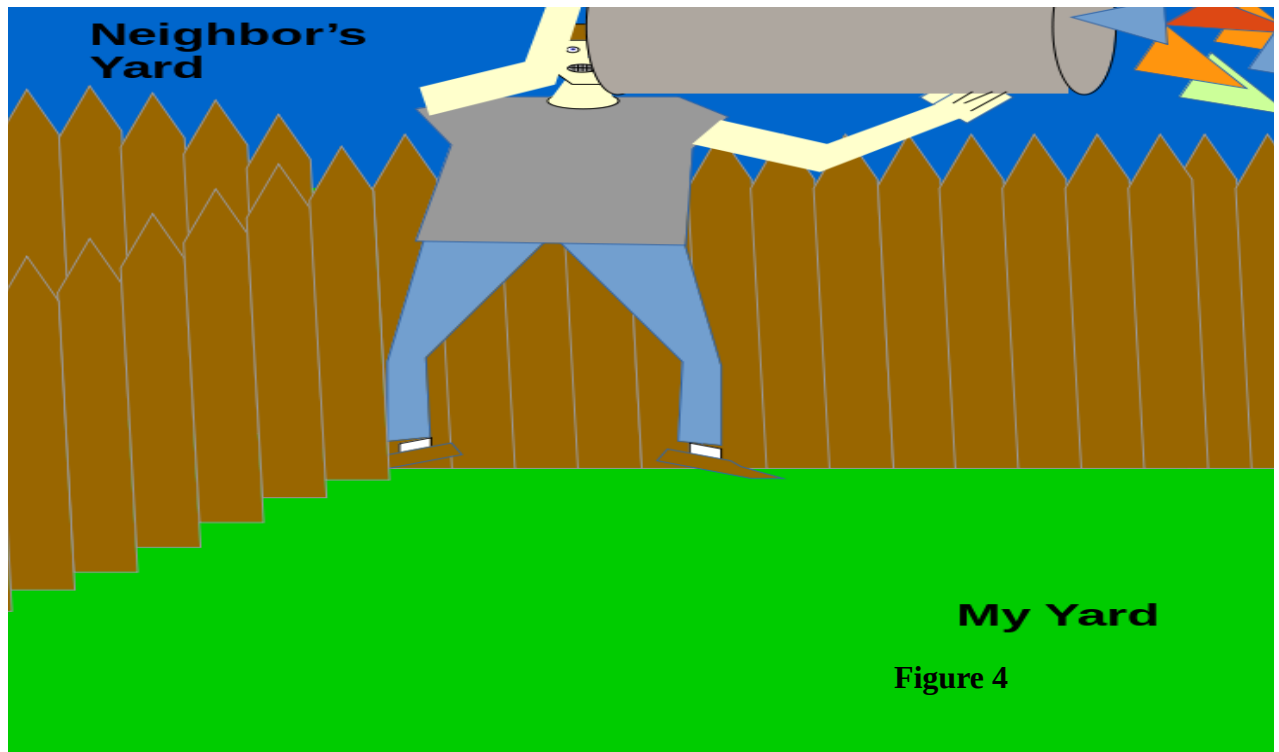
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An evaluation of the profit of a firm determines the plan for the project. If the left side of the balance (revenues) is greater than the right side of the balance (cost), the balance tilts to the left. The left tilting balance indicates the firm is profitable. The project is evaluated as creating more value than it consumes. The profit signal suggests we build more energy projects of that type. More firm entry will eventually compete away the project. If the right side of the balance (costs) is greater than the left side of the balance (revenues), then the balance tilts to the right. The right tilting balance then indicates the firm is experiencing losses. Losses indicate the firm should exit industry through bankruptcy or the sale of assets.

During the beginning of this century, a man walked his dog past the balance. He found that there were weights on the ground. Apparently there were supposed to be incorporated in the scale. But they never made it onto the scale.



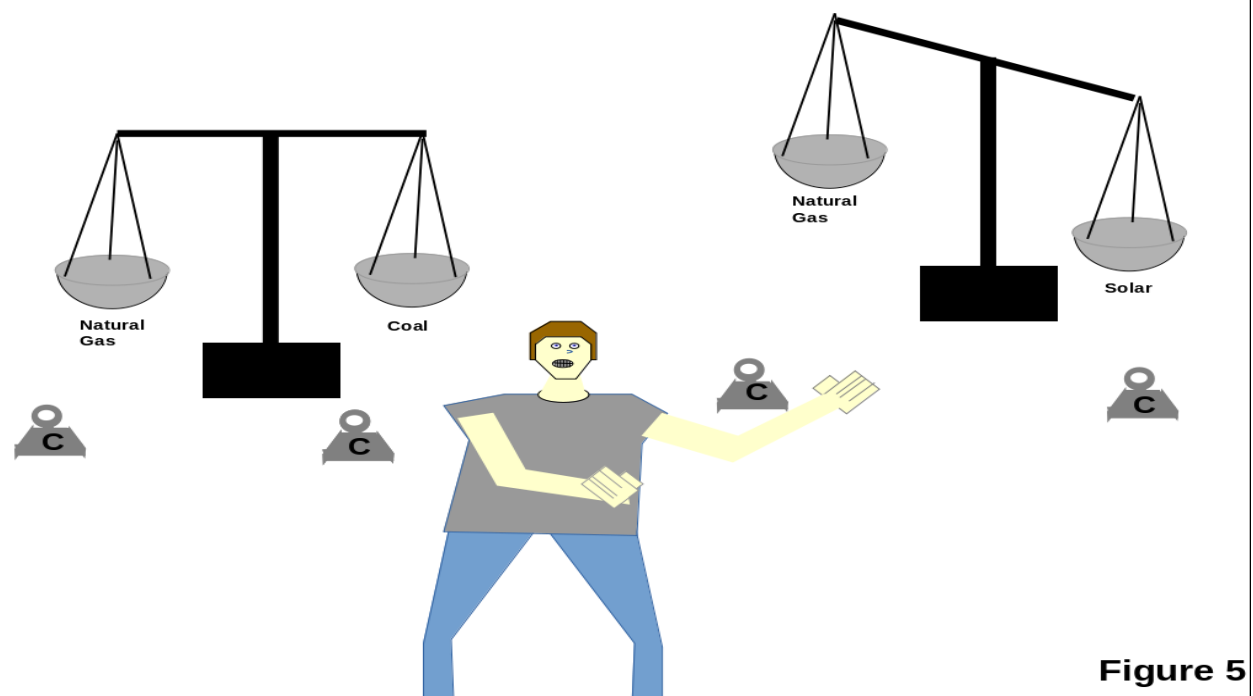
An externality is a cost or revenue that should be on the balance, but was not placed on the balance. An example of an externality is where someone throws trash on the neighbor's yard. Or in the case of carbon, an externality occurs when the cost of carbon does not get included into the cost of doing business.



Below we can see two separate scenarios. These scenarios illustrate the difference between how industries operate before the externalities were discovered and after the externalities were incorporated. The first scenario occurred during the 1990s. During this first scenario, the carbon factor was unknown. The second scenario will occur during the 2000s. During the second scenario, the carbon factor was known. We will compare the balances during each time period to see how the carbon factor would affect industry.

During the 1990s, the balance measured the outcomes of both coal, solar and natural gas as major sources of energy.

The first type of energy project evaluated by the scale of our marketplace was the choice between natural gas and coal. Before carbon had been included, natural gas was on relatively equal footing with coal. There was no strong incentive for industry to favor coal or natural gas. The weight of carbon cost was still off the scale, undiscovered by our dog-walking man. Since there was no incentive avoid the cost of carbon carbon, natural gas and coal were on relatively equal footing.

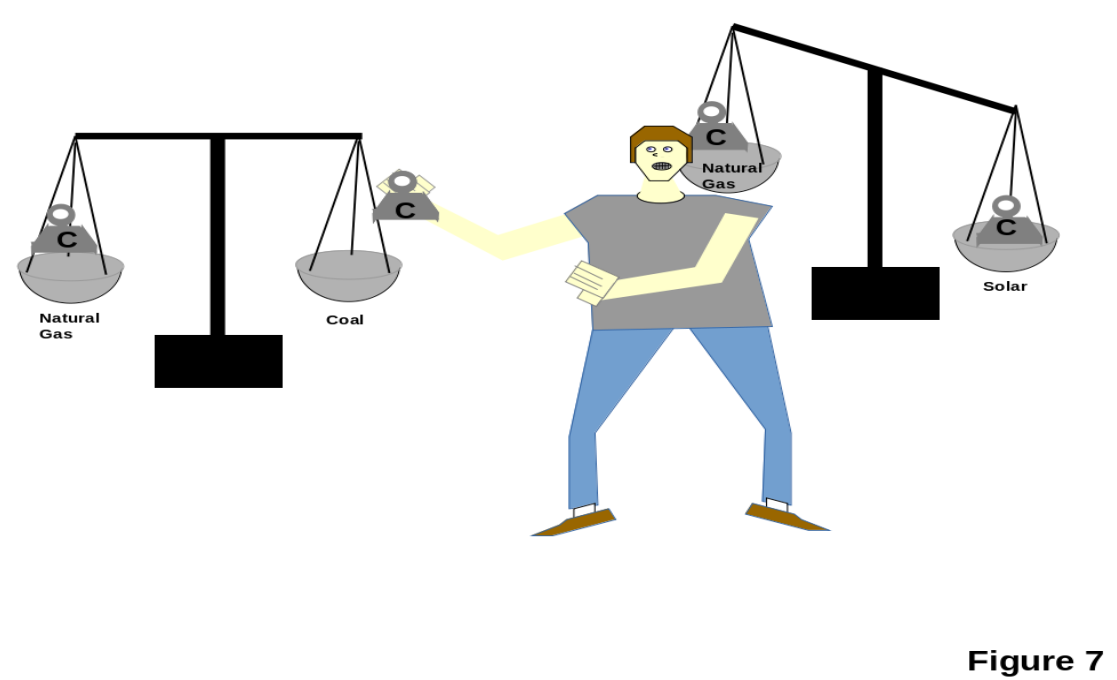
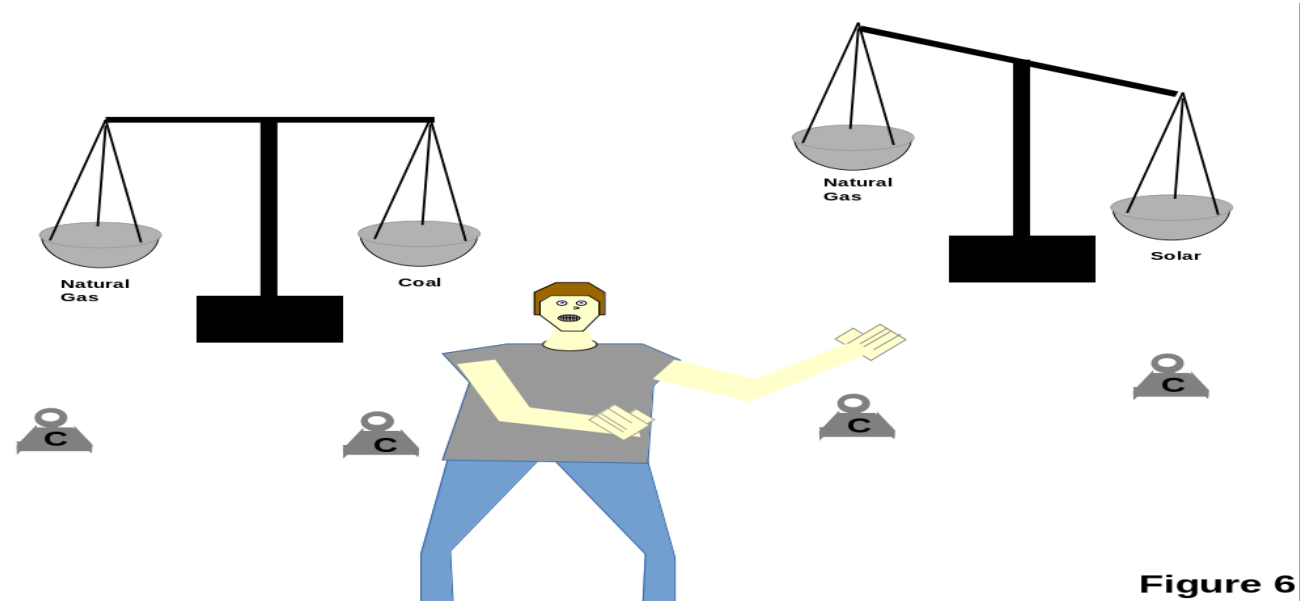


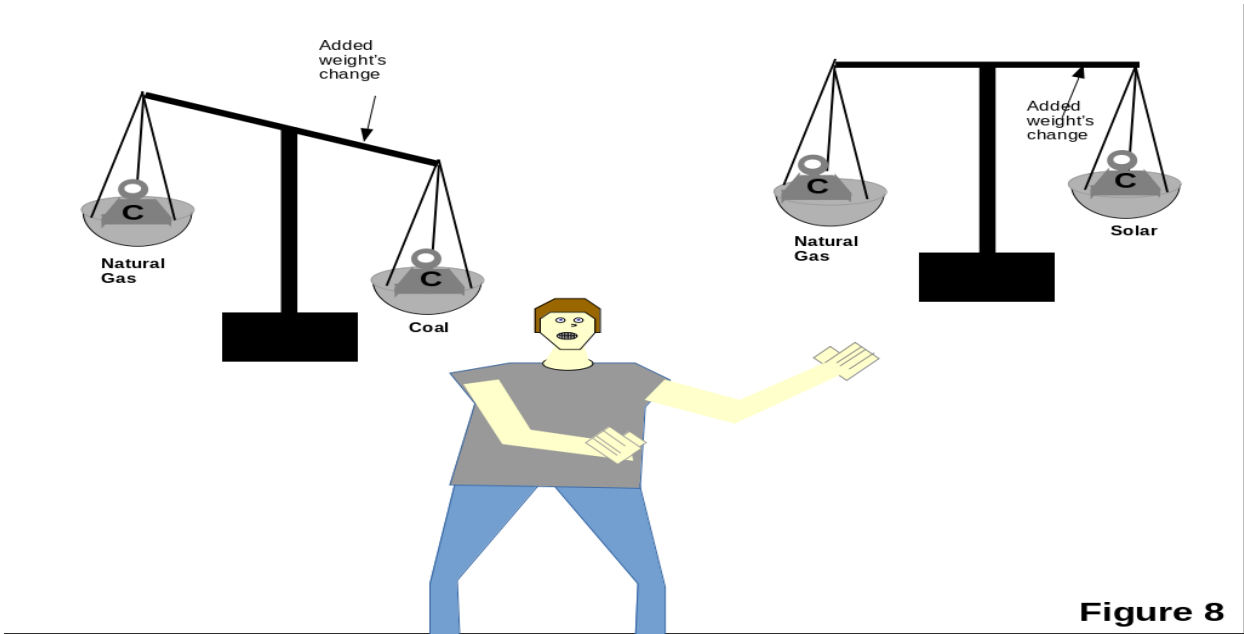
A second type of energy project evaluated by the scale of our marketplace was the choice between natural gas and solar. Before carbon had been included, solar had no way to compete with natural gas. Solar cost had not been driven down enough to become competitive with fossil fuel types of energy. Here the balance of the scale tilted toward natural gas in lieu of solar energy.

In the early 2000s, a new problem was brought to light. The risk of carbon emissions and their negative impact became known. The consequences of this newfound knowledge for industry could be dire or great, depending on which type of energy source is considered. Some might argue the problem was known decades before hand. In this particular situation, I use 2000s because that is when international consensus illustrated that global warming was an issue in their treaties

The first type of energy project evaluated by the scale of our marketplace was the choice between natural gas and coal. Now that carbon had been included, natural gas had an advantage relative to the more carbon intensive coal. There was an strong incentive for industry to favor natural gas over coal. The weight of carbon was still now incorporated onto the scale. It had been re-discovered by our dog-walking man. With carbon cost included, natural gas would be the winner. Knowing this, merchant energy companies chose to build natural gas powered electrical generating stations. These natural gas energy facilities were intended to win the energy race when the expected carbon incorporation occurred.

A second type of energy project evaluated by the scale of our marketplace was the choice between natural gas and solar. Now that carbon had been included, solar was beginning to have a chance to compete with natural gas. Solar cost still had some room to be driven down by the forces of technological advancement. Here the balance of the scale closer to equal, from its prior state of tilted toward natural gas and away from solar energy.





The transition between these two states, between the 1990s and 2000s, brought the potential for new changes to industry. New questions arose, which industry and legislatures debated. One question which arose asked industry: how to adjust the laws and industry for the newfound weight of carbon? Another question under debate: Did the need for carbon reductions really exist? Some had suggested that human caused global warming was a myth. Finally, industry was faced with the question of how to reduce the costs of our current industry.

The first question up for debate was how to incorporate the newfound costs of carbon. There are four ways to incorporate weights of carbon onto the scale of our economy's balance. The first option was the Kyoto deal. The second option was a tax on carbon. The option to use bond subsidies was suggested as a third alternative to incorporate carbon costs. Finally, the option to use altruism to adjust industry was also suggested.

The first option was the Kyoto deal. The Kyoto began in the mid 1990s. Its negotiation continued up into the 2000s. Here the treaty was a deal negotiated between nations across the globe. Its participants include both the developed world and the developing world. The first part of the treaty would have most of the developed world (United States, Europe and East Asia) agree to voluntarily reduce carbon emissions. The second part of the treaty would have most of the developed world agree to reduce emissions in a binding way. The binding part of the treaty made the emissions reductions mandatory. Most of the developed world included the developed countries with the exception of the United States and Australia. The effect of either portion of the treaty is to reduce the amount of carbon emitted into the atmosphere.

The second option on how to incorporate the cost of carbon was a carbon tax. The second option would include a tax on the emissions of carbon. That carbon tax could include a tax on emissions at different locations. Carbon could be taxed where it is emitted. Or carbon could be taxed where carbon intensive products are produced. The effect of these carbon taxes is to increase the all in cost of utilizing carbon intensive forms of energy. The effect of that increase to that all in cost of carbon-based energy is to tip the balance of energy production from their prior state. The scale of our economy's balance tilts away from coal and toward natural gas as a source of energy. The scale of our economy's balance adjust from its strong tilt away from solar and toward a weaker tilt away from solar.

**Base Case  
(Before  
Carbon  
Adjustment)**



**Figure 9**

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**Base Case  
(Before  
Carbon  
Adjustment)**

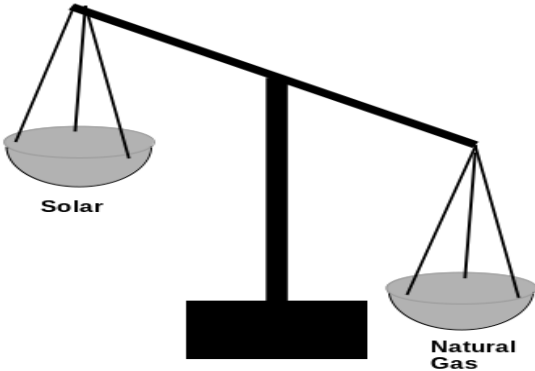


**Figure 10**

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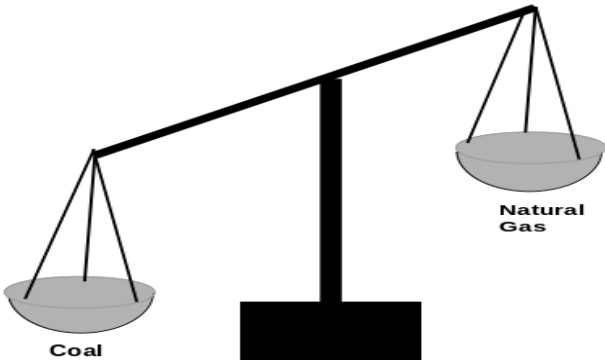
**Carbon  
Adjustment:  
Carbon Tax**

**Figure 11**



**Carbon  
Adjustment:  
Carbon Tax**

**Figure 12**



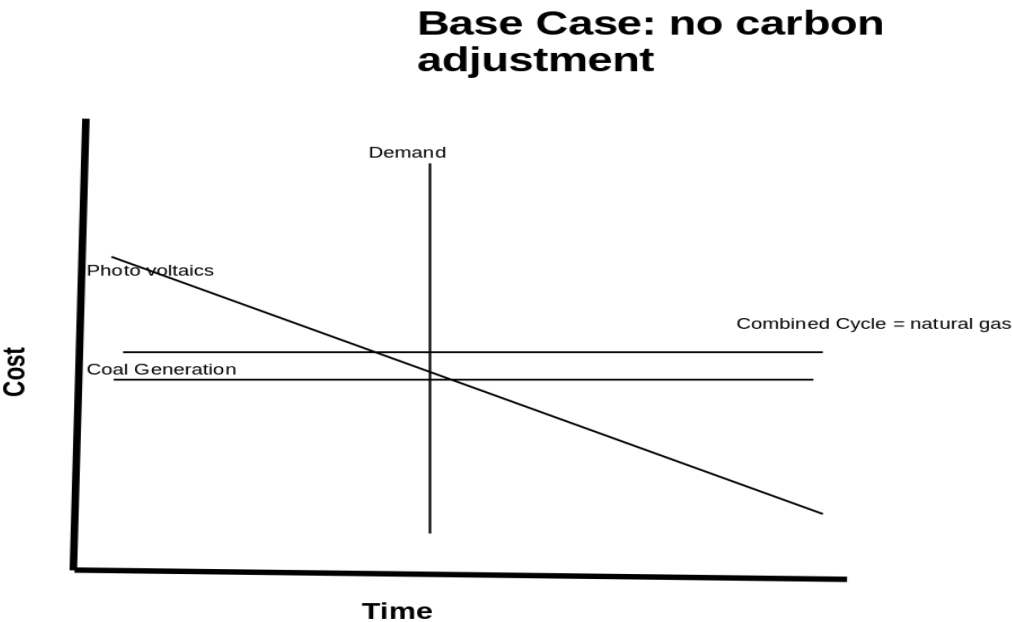


Figure 13

**Base Case  
(Before  
Carbon  
Adjustment)**

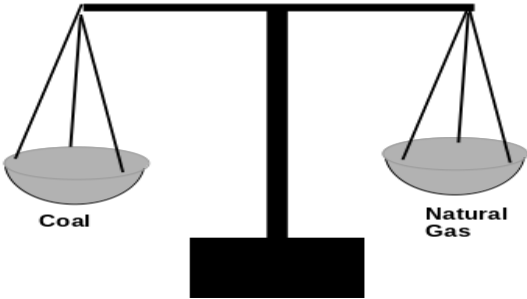


Figure 14

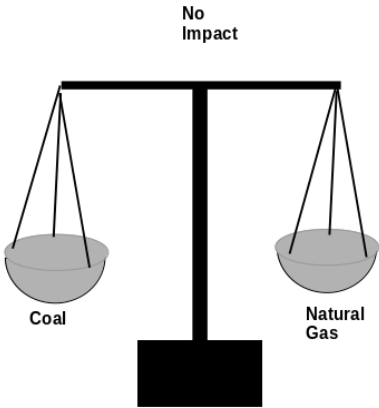


Figure 15

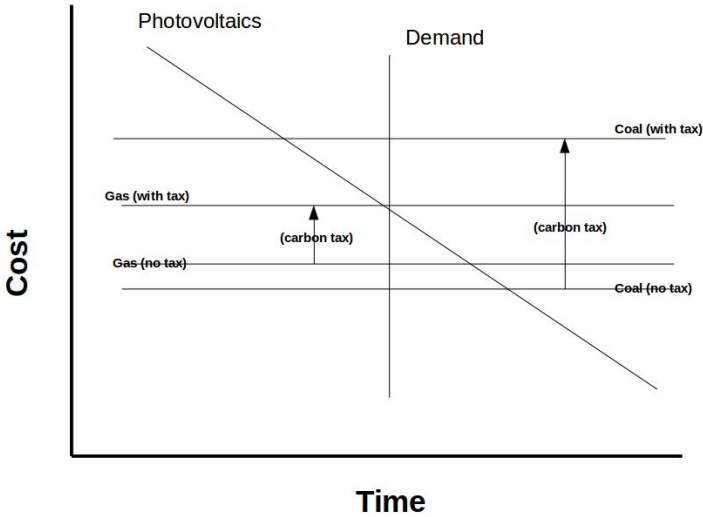


Figure 16

Another option to incorporate the newfound cost of carbon is to add to the balance the subsidy of bonds. This can be seen in the case of the various bond issues created during the 2010s. Here bonds were issued for energy type projects. These issues include solar bonds, Green Climate Bonds and various other bond types. The effect of these constructs is to give the bonds a government subsidy.

The effect of the bond subsidy is to lower the effective interest rate, and therefore the effective cost of capital applicable to those bond issues. The lower cost of capital applied to renewable types of energy should tip the scales of our economy away from carbon intensive sources of energy such as coal and natural gas, and in favor of solar and wind energy.

**Base Case:  
Before Carbon  
Adjustments**

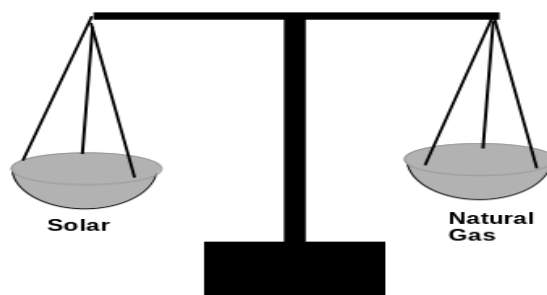


**Figure 17**

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**Carbon  
Adjustment:  
Bond Subsidy**

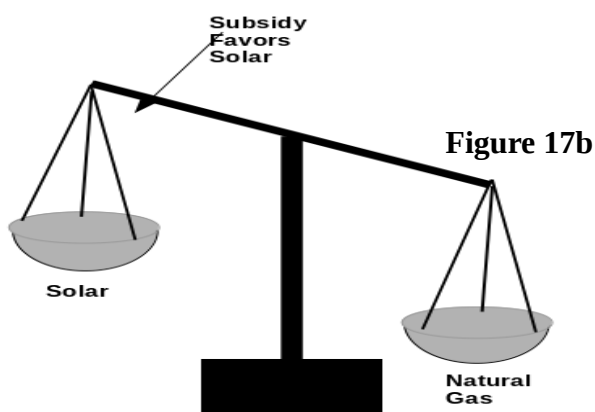
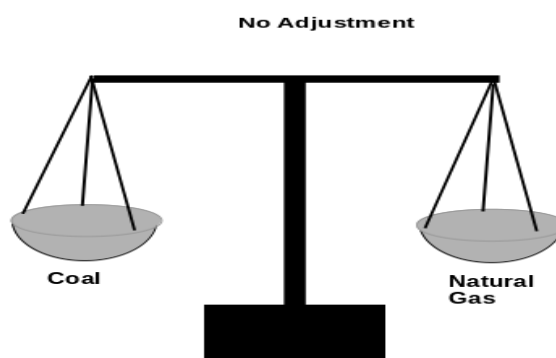


**Figure 17b**

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**Carbon  
Adjustment:  
Bond Subsidy**

**Figure 18**



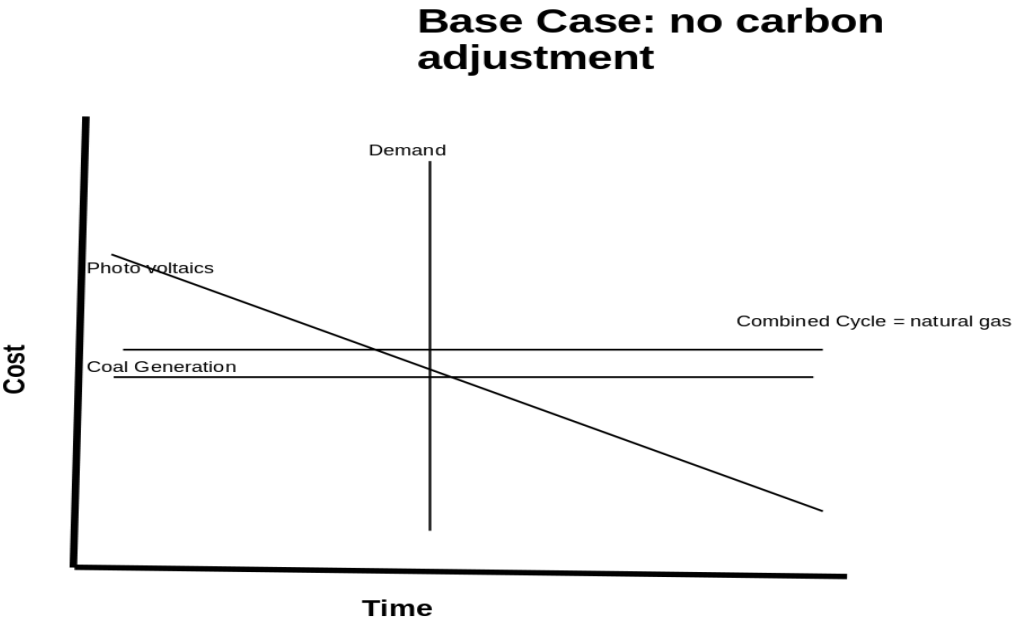


Figure 19

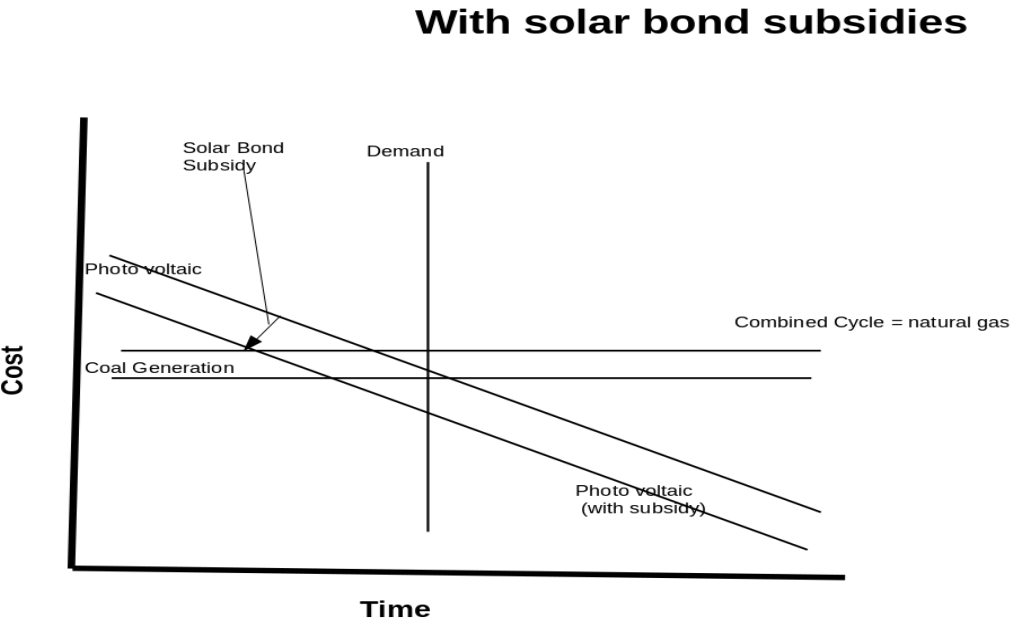


Figure 20

A fourth and final option to adjust industry is the use of consumer and corporate based altruism. The effect of this type of altruism is for environmentalists to persuade consumers to ignore the cost of energy and volunteer their extra dollars in a display of altruism. The effect of this type of activity is to create off-scale activities which exist outside the balance of our economy's value measuring system. The benefit of this approach is it offers an alternative to uncooperative law making bodies. The problem with this approach is that it unfairly taxes the good Samaritans and unfairly benefits the freeloaders.

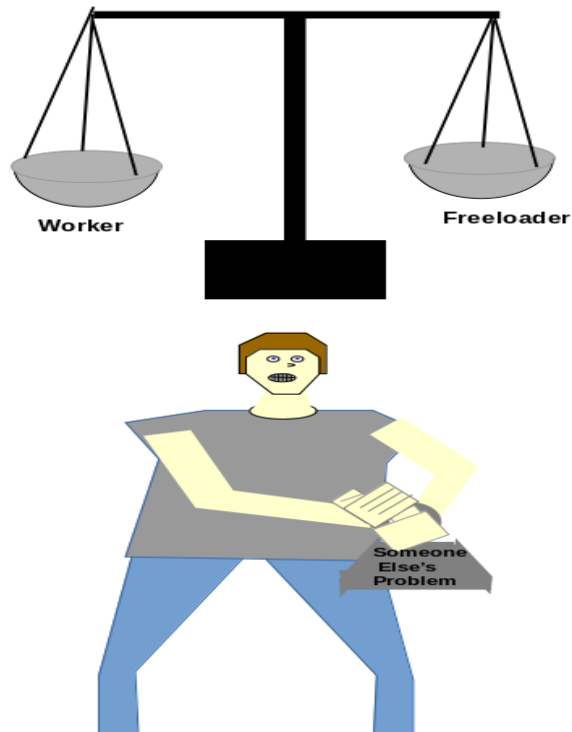
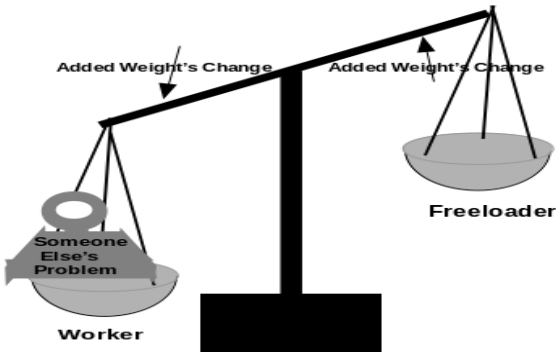


**Figure 21**



Being Too Nice

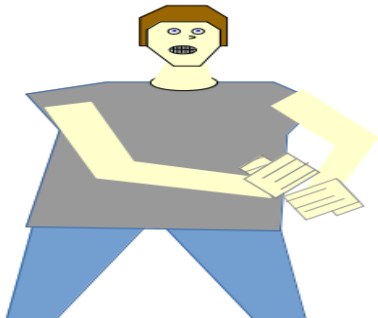


Figure 22

A second question up for debate was does Global Warming even exist? The theory of Global Warming could be taken for granted as true if we only look at scientific consensus. Many of us do take the scientific consensus for granted as true. Others question and distrust the scientific establishment, resisting scientific theories and their assumptions. Examples of debates where scientific consensus is not taken for granted include debates over evolution vs creationism, is artificial intelligence coming?, and does global warming exist? Reasons to question the scientific establishment include: past bubbles created by scientists that did not occur include year 2k, too cheap to meter, artificial intelligence, and cold fusion. In each of these bubbles scientists made claims and expectations which did not occur.

The first scientific bubble was the y2k bug or year 2000 bug. This situation was the fact that computer programs were written back in the 1960s and 1970s which were not expected to live past the year 2000. With that expectation and the need to conserve limited computer memory, the dating convention was only built to include 2 digits for the year. The software from the past outlived their expected life. Going into the year 2000, a concern among computer scientists was that the underlying software running our country and infrastructure would fail when the time in the computer exceeded the software's upper time limit. This bubble turned out to be overblown. When the year 2000 passed, little of the catastrophic theories of Y2K bug occurred. No planes fell from the sky. No trains ran off their rails. A scientific bubble was found to be overblown.

The artificial intelligence boom expected of the 1980s was a scientific expectation that did not play out. This scientific establishment had an expectation that artificial intelligence would cause human-like robots to take over. This can be seen in the movies like Star Wars, Short Circuit, and other films of the past which show robots with human-like qualities. The expectation for Artificial intelligence did not turn out as well as expected. Artificial intelligence did have a few capabilities which could recognize handwriting and a few other narrowly defined human tasks. But the bubble burst when artificial intelligence failed to meet the unrealistic expectations of its scientific bubble.

Too cheap to meter was a slogan used in the electrical power industry during the 1950s. Early nuclear power plants proved to be a seemingly unlimited source of cheap energy. With such limited fuel cost, Nuclear power was expected to be "too cheap to meter". This meant that the cost to produce would be so small it would not be worth the effort to meter (or measure) the electrical consumption needed to determine the customer's bill amount. Early expectations were found unrealistic when cost overruns for building, site restrictions, waste handling problems, and other issues drove up the cost of Nuclear Energy. Another scientific bubble popped.

The final scientific bubble considered was the brief cold fusion bubble. Here cold fusion was found by a pair of scientists. These scientists thought they had found cold fusion in their lab. Of course the early media reports showed cold fusion as a real possibility. Later on, other scientists failed to reproduce the same results. Here they determined that the first finding of cold fusion was a wrong conclusion. The fourth and final scientific bubble had burst.

Here we have considered and analyzed four past bubbles of scientific phenomenon. It is the background of this scientific bubbles that an outside observer might find it expedient to question the Theory of Global Warming, and media accounts of its catastrophic phenomenon. These bubbles give reason to question both 1) that global warming exists and 2) that if global warming does exist, then the accounts of its damage may be exaggerated.

Above we have fully covered the side of argument against global warming and carbon as its cause. This book does not cover the arguments in favor of Global Warming. Since the scientific establishment has already covered the evidence and arguments in favor of global warming so thoroughly, I'll direct the reader to academic journals if they seek that information. Even though the arguments in favor of global warming were not covered here, their implications were not overlooked in

the final assumptions regarding carbon tax / adjustments and their impact on the scale of our economy's energy balance evaluation.

### **The Debates**

The venue for these debates within industry took several different venues. Arguments over carbon emission often occurred in the courts. The arguments also occurred over international treaties.

Examples of court battles which faced the energy industry include the battle over the EPA and courts. The battle over the EPA ruling was a court battle which fought over which government agency would have the right to regulate carbon. Since the democrats had not achieved their desired result of a carbon tax imposed by the legislature, they sought a carbon tax imposed through the court system. The EPA or environmental protection agency already had the right to regulated SO<sub>3</sub> and NO<sub>x</sub>, common emissions from coal plants. A natural next move for the democrats was to seek similar environmental regulation as in other emissions, only in this case the emissions were for carbon. Other court battles included lawsuit challenges. These lawsuits sought to press charges seeking damages for the expected damages caused by carbon emissions.

International treaties also took place to settle the carbon emissions issue. The carbon emissions were negotiated at the Kyoto Treaty. The purpose of this treaty was to coordinate internationally the reduction of carbon emissions. The goal was to limit temperature increases to 2 degrees. The agreement included voluntary and mandatory restrictions in the amount of carbon emissions by nation.

### **B) Technology under-developed**

Another issue faced was how to reduce cost of new energy technologies when applied in current industry. Various technological issues can impact our use of carbon. A decline in cost curves for solar and wind turbines could make these renewable energy sources a viable alternative to conventional sources of energy. Technologies such as carbon sequestration could reduce the carbon emissions impact of fossil fuels. Finally, cleaner coal technologies have the potential to reduce carbon emissions.

Technological change can impact the cost curves of renewable types of energy. Cost curves for renewable energy types like wind and solar both decline the costs of energy over time. Various changes within the manufacturing industries cause the costs to produce and install those energy types to come down. As of the 2010s, the costs of wind and solar energy types were still too high to compete with conventional fossil fuels. The installation of wind and solar required subsidies to make up for their lack of natural cost advantages.

Technologies such as carbon sequestration offer a source of carbon emissions reduction. Carbon sequestration is the technology which pumps carbon emissions from the emissions of carbon combustion out of coal facilities and into the ground. Deep in the ground in underground formation there are geological formations which can contain gas. Before the formations are accessed through oil drilling type technologies, porous geological topologies had been formed to contain gases. If old oil reservoirs of the sort could be filled with carbon containing coal facility emissions, than the net carbon emissions of coal facilities can be reduced. This technology is not without its limitations. It is possible that leaks could negate the benefits of carbon sequestration's potential.

A third and final type of technological opportunity is the potential for cleaner coal. Clean coal facilities are technologies which allow coal to be burned in cleaner ways. The processes which burned coal in the past produce more emissions than more advanced coal burning technologies of the future. IGCC is integrated gasification combined cycle. It enables carbon monoxide to be converted to carbon dioxide, a better preparation for sequestration. Although they do not reduce coal emissions in their entirety, clean coal technologies may offer some benefit for emissions reduction needs.

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Below are a series of diagrams of balances. They illustrate the different outcome of energy balances.

## **ELECTRICAL INDUSTRY: COPING MECHANISM**

### **Chapter Summary**

Our system has several coping mechanism to deal with the problem of carbon externalities. The Kyoto treaty was one of the proposed solutions to the inefficiency of carbon. It offers treaties and ways to reduce the amount of carbon and its impact on global warming. Beyond that, various taxes, subsidies and altruism schemes offer other alternatives to Kyoto.

#### **Kyoto Treaty**

The outcome of the Kyoto deal leaves issues unresolved. Unresolved issues include the failure of the United States and Australia to stay in the mandatory protocol process. The refusal of these participants to engage in deeper treaty requirements is driven by structural defects within the treaty and its fit within our economic system. The voluntary nature of their treaty participation invokes problems with their altruistic approach. In order to better understand the situation, we will engage deeper in analysis of the following four issues. First and foremost we will evaluate the failure of the United States and Australia to engage in the mandatory treaty, along with the reason's we withheld from those treaties. Second we will review the effect of the Kyoto treaty on carbon reduction. A solution will be proposed to cover the flaws in the current structure of the Kyoto treaty. And finally matrices will be reviewed to illustrate the options and effects of each of the option to resolve the treaty problems.

The first issue of relevance is the failure of the United States and Australia to join the mandatory portion of the Kyoto treaty. The failure of these two major industrialized nations to engage offers a major blemish to the international unity offered by the treaties. Reason for the holdouts to the Kyoto treaty include the uneven application of that treaty to developed and developing world, the danger the one-sided treaty would send jobs overseas, and effect of exporting carbon intensive industry

overseas.

One of the problems with the Kyoto Protocols was the uneven treatment of nations. Developed nations would be expected to contribute to the treaty by reducing their carbon emissions. Developing nations were allowed to avoid contributing emissions reductions. Developing nations include the less developed nations of South America, Central America, and Africa. Developed nations are the rich nations such as the United States, Europe and East Asia. The uneven treatment of nations would be detrimental to developed nations when the competitive nature of international trade was faced with Kyoto regulations.

A potential problem with Kyoto in application was the danger that uneven application of environmental regulation would cause carbon intensive industries to move from developed nations to developing nations. The total amount of emissions worldwide could very well stay the same under Kyoto and the unevenly applied regulation could redistribute carbon intensive industries from the developed world to developing world.

The Kyoto Protocols failed to address the issues raised above. It was these failures which drove American and Australian hold outs from full participation in the Kyoto Protocols. The United States was a world leading nation. Australia is its own continent. These two substantial nation's holdout from Kyoto limited the Protocol's ability to enact changes. There were voluntary reductions in each country, despite the lack of conformity to mandatory standards.

Certain portions of the developing world did not reduce carbon emissions. In fact, these developing world nations increased their carbon emissions during the time period of the Kyoto Protocols. These developing world nations included that nations of Central and South America, the nations of Asia and Oceania, and the nations of the Middle East.

The flaws which affect the Kyoto treaty of the past caused the holdout of the United States and Australia. The flaws were that Kyoto allowed the developing nations the option to reduce emissions, but that option did not apply to developed nations. This gap in regulatory coverage was a huge differential which would open up the potential to arbitrage away jobs and industry by shipping them overseas. A solution to the treaty's problem would be a recreation of the old Kyoto treaty in mostly the same form it had existed in the past. The difference here would be to add trade restrictions to prevent carbon intensive industries from moving. If that trade restriction were specific enough to block only the off-shoring of carbon intensive industries, then the new Kyoto Protocols could meet the needs of the United States and Australia to inspire full compliance with mandatory portions of the Protocols.

The matrices in this chapter illustrate how those incentives will be adjusted.

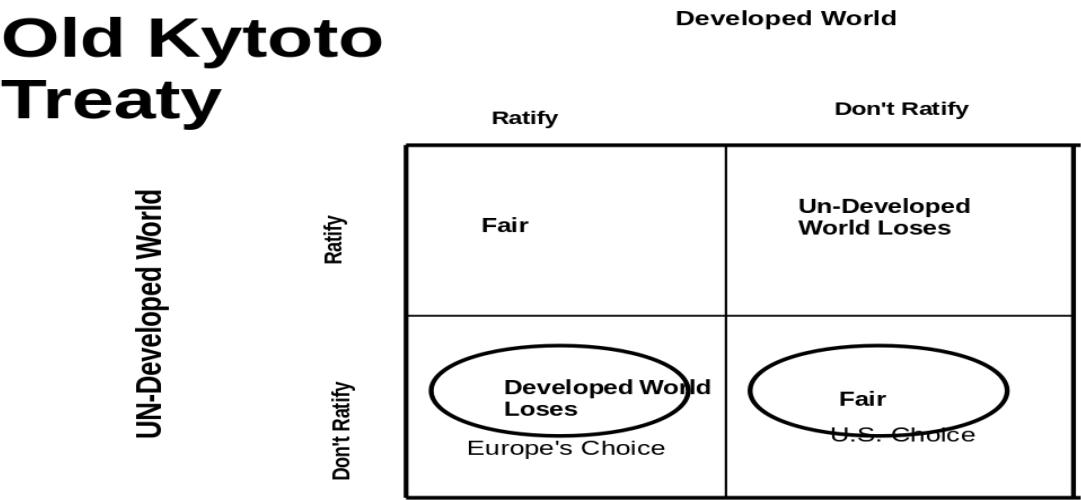


Figure 23

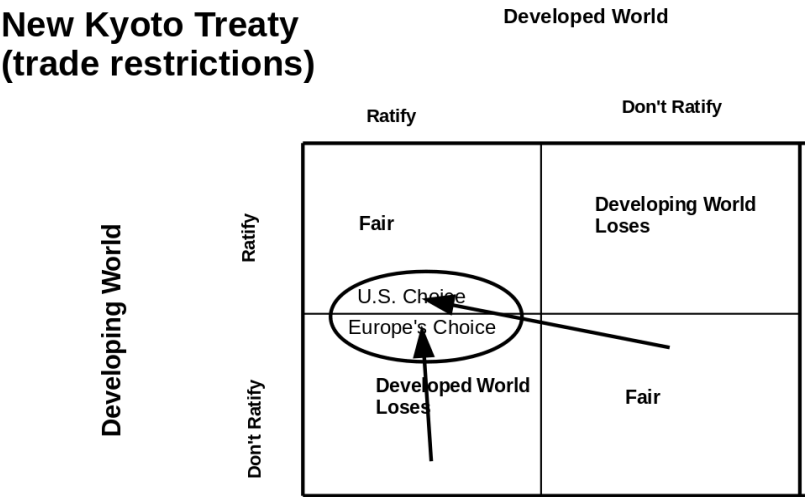


Figure 24

Above it has been shown that through the correct structuring of treaties, more nations can be brought to meaningful participation. With the treaties in order, a remaining problem to address is the need to fix defects in industry.

Our industries and our civilization are built upon a series of embedded assumptions and rules which have been used to order our society. As we can see in history, it is inevitable that we will re-argue those theories back and forth into and out of style as new schools of thought come into play. Examples of industry organization being put into play and removed from action include: the advent of corn laws to create free trade in Great Britain during the early 1800s. This trend was later countered by declines in free trade following the 1929 market burst. This can be seen in the tulip bubble rise during the 1600 when the price of a flower exceeded the price of a 12 acre plot of land in Holland. The industry rules were then changed back again when that bubble burst shortly thereafter.

A modern version of this phenomenon can be seen as the photo voltaic bubble reached its peak with the advent of Swanson's Law and the creation of photo voltaic subsidies during the 2000s and 2010s. The falling out of that industrial trend will be seen in the reversal of this photo voltaic industry bubble with advent of Swanson's Law Unraveled. In the SLU chapter of this book, you will find the arguments needed to snap back the photo voltaic industry out of its bubble.

# SEMICONDUCTOR INDUSTRY: TECHNOLOGY INEFFICIENCIES

## Chapter Summary

Moore's Law is a learning curve for transistors. The transistor is the building block for the computer hardware which makes up the integrated circuit. There are inefficiencies in the technology capture and creation mechanisms within our economic system. These drive inefficiencies in the misallocation of STEM labor.

### **Moore's Law**

Moore's Law describes the exponential decline in price of transistors. The transistor price decline can be explained by the increase in wafer size, the reduction in silicon prices, and a reduction in transistor size.

The wafer is the name of a thin circle of silicon. This forms a basic unit of the transistor manufacturing process. The wafer's increase in size over time is one of the drivers of cost reduction within the semiconductor industry. An increase in the wafer size, as measured in diameter by millimeters, has increased from 200mm, to 300mm, and finally to 450mm. These increases in diameter had a subsequent increase in surface area for each silicon wafer. The surface area's increase allow more transistors to fit on each wafer. And fewer batch transitions enable better use of semiconductor manufacturing processes.

Silicon prices have declined as well. Declines in silicon prices can be attributed to improvements in the manufacturing and purifications processes for silicon. These lowered prices for silicon are cheaper feedstock for the solar cell manufacturing process.

Transistor size has declines as well. The decline in transistor size has been driven by improvements in semiconductor manufacturing. Declines in the dimension of each transistor reflect improvements in semiconductor manufacturing equipments, and improvements in materials. In the manufacturing process for transistors, light is used to create the patterns which generate transistors. Lower wavelength light enables lower dimensions. Improvements in polymers for semiconductor

manufacturing enable the manufacturing to coordinate at a lower wavelength.

A smaller dimension for the transistor enables more transistors to be placed on each wafer. That lower dimension has several beneficial impacts. Smaller dimensions allow more transistors to be placed on each wafer, economizing use of scarce wafer surface area during the manufacturing process. Smaller dimensions also allow for better electrical properties of integrated circuit features. Smaller dimensions alter the electrical properties of the circuit elements, enabling higher frequency for circuit operation. Higher frequency for the circuits speed up your computer chips.

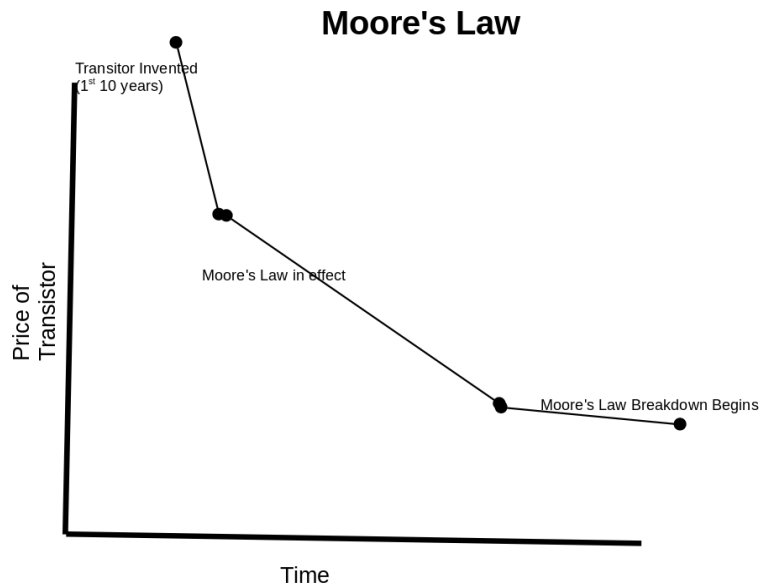


**Figure 25**

The chart above shows the effect of Moore's law on transistor price over time. Two portions of the trend are illustrated here. The first portion are the initial period when the transistor was invented. The second portion shows the positive effects of that invention generating value for decades afterwards. The third and final section shows the breakdown in Moore's Law in the later years.

Moore's law was a success. Most of the success originated at the origin of Moore's Law's trend. But following that initial success, much inefficiency has formed around the semiconductor manufacturing process. There is a huge mismatch between technology creation and technology capture within the industry. That divergence, the mismatch in value creation and capture leads to mis-allocation of scarce resources.

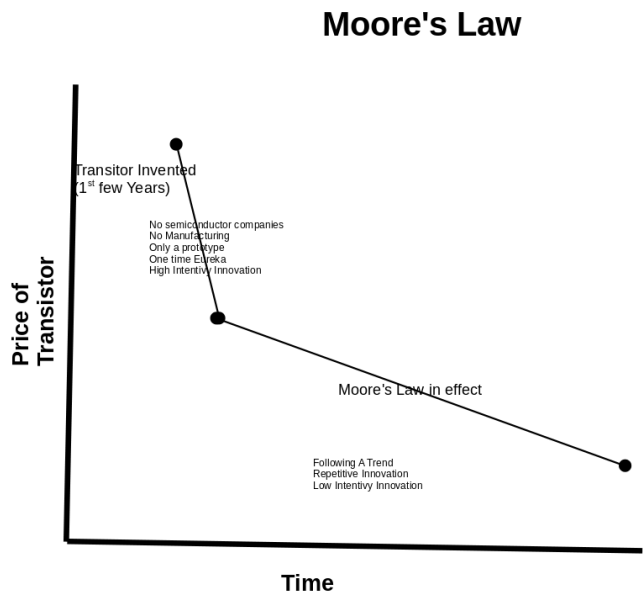


Figure 26

The chart below illustrates the mismatch in labor and opportunity.

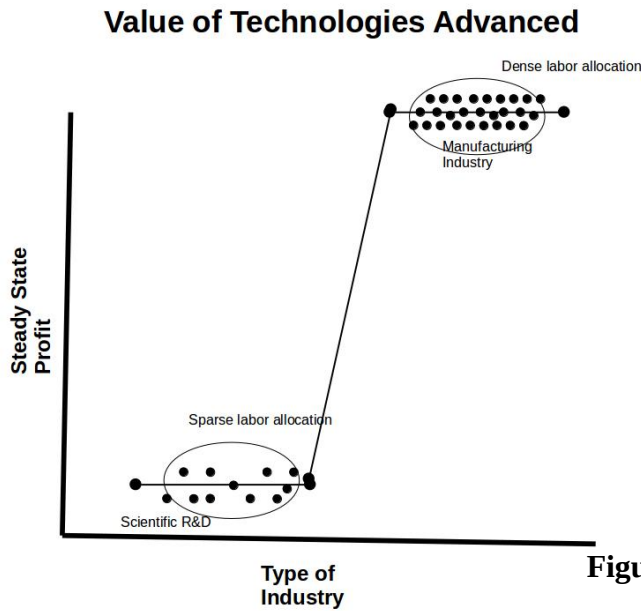


Figure 27

### **Technology creation-capture divergence**

The divergence is that technology creation and technology capture are two separate events. Two segments of Moore's Law, shown on the chart below, have two divergent trends. Each trend has different driving forces and types of innovation. The first segment occurred during the first few years of the invention and implementation of the transistor to integrated circuit manufacturing. Here a high intensity of innovation occurred in one short moment of time. That moment of innovation was difficult to reproduce. That value created at that moment of innovation was incredibly high, although the component of value captured was incredibly low. The following decades after that founding moment saw technological innovation of lowered intensity. This second period created only a small amount of value, but captured an enormous amount of value. The divergence of separation between technology creation and technology capture created an inefficiency in the market.

To better understand what is going on, we will cover the two periods of innovation seen in the semiconductor industry. We will create an indicator, which seeks to identify some attributes of innovation value. It is important to note that this is only an indicator of technological value, and not a perfect test. The imperfectness of this test means caution should be used if it is reapplied out of context.

The indicator to approximate technological innovation is ease of reproduction. It is an estimate based on two factors. Factor one is the time required to retrain a person to repeat the same task. The second factor is reliability (as a percent of trials) where factor one can be reproduced successfully.

Based on these factors, we can analyze the value of the transistor invention. The first factor is the time required to retrain the person. In the case of the transistor, the inventors were educated with a PhD. And also, he had years of industry experience. This suggests a long time necessary to train the inventor of the transistor. This first factor is in favor of high value for the transistor. The second factor asks, how reliably can a transistor type invention be recreated successfully? It has been so many decades since the last transistor level invention was created. The long time suggests a poor match for factor two. From these two results, we can conclude the transistor was an incredibly valuable invention.

Using the same factors, we can analyze the innovation of the subsequent phases of semiconductor manufacturing. The first factor suggests the time to train an operator of the semiconductor manufacturing process is much lower. An operator of manufacturing equipment needs only a two year degree and a few years of training. The second factor suggests a high reliability of trainees entering semiconductor manufacturing industry. These two factors suggest a low amount of innovative intensity for the second period of the chart.

The mismatch of these two periods causes value creation and value capture to be off. It also causes labor to allocate to less than optimally useful portions of the value chain. What this means for the value chain is that the activities of technical innovation, which are the initial founding moment of the semiconductor industry, are under funded. The manufacturing line, and subsequent minor technical innovations after the founding moment are over funded. This mismatch of funding causes STEM (Science, Technology, Engineering, Math) labor to be overcrowded at the site of manufacture. Here STEM labor causes the manufacturing process to be over-scienced. Because such enormous amount of funds collect at the location of manufacture. At research facilities for Research and Development, STEM labor is scarce and underfunded. This overallocation and under-allocation of resources causes the density of STEM labor to oppositely mismatch the needs of industry. Within the manufacturing facilities, you can see the STEM labor often artificially creates needs for its ability to fill that gap. This gap in expectation and reality can be attributed to both over-education for that portion of the value chain and the already complete nature of that industry's technological innovation. And that gap is filled with invented needs and work.

### Charts of Labor Mis-allocation

The chart below shows an S shaped curve. That S shaped curve illustrated the value creating potential of different segments of the semiconductor manufacturing industry. The horizontal lines up to the curve represent the allocation of labor, and its density, on each part of the value chain. As you can see, the lower portion of the S has a high density of STEM type labor. This reflects the high density of STEM type labor within the semiconductor manufacturing industry. The upper portion of the S has a low density of STEM type labor. That low density has occurred where new transistor type prototypes would be created. The density of value creation potential mismatches the density of the resources. This mismatch is an inefficiency in our system.

The chart below shows another S shaped curve. The y-axis is the total value profit. The x axis denotes labor usage. The shaded area #1 shows the optimal configuration of labor. When incentives are properly aligned, STEM labor resources allocate first to the most valuable areas of industry. The shaded area #2 shows the anti optimal configuration of labor. When incentives are poorly aligned, STEM labor resources allocate first to the least valuable areas of industry. The shaded area #2 reflects the current situation within the semiconductor industry reflected by the inefficiency and mismatch described above.

The chart above covers below allocation. Both optimal and anti-optimum are illustrated.

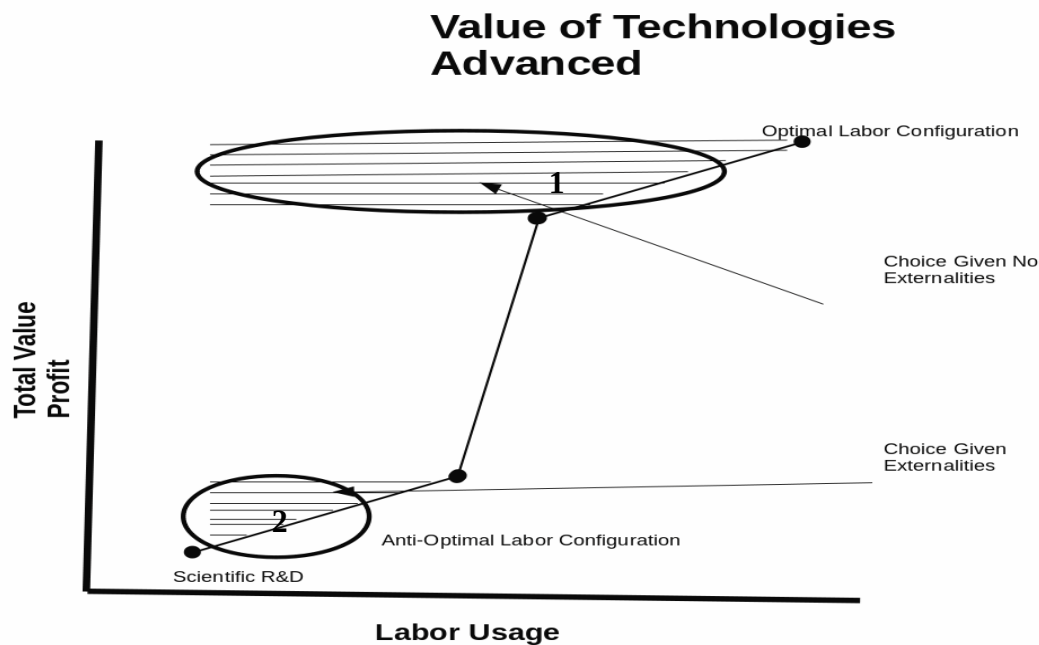


Figure 28

We can ask again why is the labor allocation of STEM resources so inefficient? And the reason for this is that the incentives of our system does not reward value creation. It rewards value capture. There is a distinct difference between the two. Labor current fills the highest labor use as measured by

steady-state profit of industry. That labor's incentive fails to take account for the externalities.

In order to fix the system, we must fill the externalities. If we were to fix the system, the STEM labor would reallocate to Total Value Profit, with no externalities.

Our current system has inefficiencies because the system does not capture externalities. Here STEM inefficiencies are the result of externalities. To eliminate the inefficiencies, we must incorporate the externalities. To incorporate the externalities, we must understand the two types of profit and how they affect the economy for STEM labor. The first type of profit is steady-state profit. It is a proxy for the type of profit our current industries most closely resemble.

Another type of inefficiency faced by our system are inefficiencies related to the academic experience. Here academia instills high expectations which cause STEM type occupations to generate artificial demand internally. Here high expectations for STEM value, as instilled by our educational system, is met with mismatch in industry. Manufacturing industries have low need for STEM type activities. High expectation, combined with low industrial need, cause that gap to be filled by artificially creating needs for the STEM type activities. In a world where mis-measures and out of context mistaken assumptions are the rule, over-optimistic in expectation drives mis-allocation in labor activity.

Above the description of inefficiencies has brought up new words. To explain better, we will define those new words. Two types of profit are proposed. The first type of profit suggested in steady-state profit. The second type of profit is total value profit. Steady-state profit is the profit which occurs when no intellectual property is taken into account, and capture for industry in intellectual property is weak. This is the model used for our current system. The second type of profit is total value profit. It is an ideal type of profit with perfect capture of value. It assumes all accounting, all economic, and all intellectual property systems work efficiently without any externalities. It is an ideal state, brought up to represent a goal for efficiencies.

### **Suggestions for Improvements**

In order to improve our current system for more efficiency, this book will cover two options. The first is an option for socialism for STEM type labor and activity. The second is a improving of our old system, to improve its efficiencies. A review of this options will offer solutions for future industry and proposals.

The first option is socialism for STEM activity. Here by STEM activity we mean the activity of science, technology, engineering, and math which typically drive technological innovation. The types of labor which make up STEM activity include only a few percentage of our entire labor force. Socialism is government ownership of the means of production. This arrangement is suitable when high fixed costs and low variable costs combine with difficult to administer property systems like scientific activity. The alternative arrangement is capitalism, where private individuals own private property and the means of production. The capitalism works well when property systems function well.

A benefit of this type of organization is that it may work better in situations like semiconductors when value capture does not match value creation. Here steady-state profits as currently realized in industry fail to allocate credit properly for value creation. If this activity were in place, then it may be a way to reallocate resources more optimally. See the chart above, where resources could be reallocated away from inefficient state in shaded area #2 above and toward the more efficient allocation available in shaded area #1.

The second option is to improve upon our current system, which is operating sub-optimally.

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The purpose is to enable the better capture of value. Improvements would be needed to bring the system from shaded area # 2 in the chart above to shaded area #1 in the chart above. Systems which could use improvement include the system of intellectual property, the system of accounting, the system of economics. These systems, if improved, could better incorporate externalities.

The goal here is to upgrade capitalism, where private individuals own private property and the means of production. The capitalism works well when the property systems function well. A better functioning property system would better incorporate externalities. It may be that this type of system is difficult to capture well for STEM types of activities.

Historically, military and government agencies have funded STEM types of activities. Organizations like SPACEX seek to privatize industries previously dominated by the government. In order to do so, it may be necessary to adjust these systems. Once private organizations have fully incorporated externalities, they can better allocate STEM type labor.

# **SOLAR ENERGY: SWANSON'S LAW UNRAVELED**

## **Chapter Summary**

Swanson's Law describes the learning curve for the photo voltaic industry. It shows how the price of photo voltaics the building material of solar cells, declines with increasing production. Certain false notions underly Swanson's Law. By pointing out the flaws in Swanson's Law, we can come to a better understanding of use of industry resources.

### **1. Introduction**

The decades from 1990 to 2018 saw the expansion of solar cell infrastructure. During this time period, most solar projects were too costly to compete with conventional energy sources. In order to accelerate investment into out of the money solar infrastructure, state and national governments provided subsidies to these projects. These government projects and subsidies were driven by the logic of Swanson's law and the domestic infant industry argument. The flaws in these two arguments for government subsidies lead to a mis-allocation of scarce resources. A better understanding of these flawed arguments and their application can be used to improve future government policy and investment decisions.

### **2. Flaws in Swanson's Law**

Swanson's Law is a rule which relates the growth in photo voltaics industry to the drop in prices. Originally named by the Economist, Swanson's law draws a link between the Cumulative Module Shipments of photo voltaics to the decline in module price. Here it appears that increasing cumulative module shipments caused the decline in module shipments. The truth is that more causation for the decline in cost of photo voltaic modules can be attributed to sources outside the photo voltaic industry.

To find the real driver of cost reduction we must look into the solar module manufacturing process. An understanding of the manufacturing processes and their economic drivers will reveal the flaws in Swanson's Law. The manufacturing processes for high purity integrated circuit silicon and

low purity photo voltaic silicon are linked. The photo voltaic quality silicon is secondary to the high purity silicon used for integrated circuits. The secondary status of photo voltaic quality silicon stems from its role in the process which purifies silicon. In this silicon manufacturing process, photo voltaic quality silicon is a feedstock to Integrated Circuit quality polysilicon.

For the majority of their history, high purity silicon used for integrated circuits has been the primary driver in the manufacturing process. Integrated circuit quality silicon has dominated the manufacturing process because of its much higher price. Integrated circuit quality silicon has also contributed more volume than its low quality counterpart for most of its history. The dominance in volume and prices of high purity silicon has caused the net-back for integrated circuits to drive the improvements in the manufacturing process for most of its history.

### **3. How those flaws mis allocate resources**

The flawed logic of Swanson's law caused the government to subsidize solar energy infrastructure. One example of these subsidies are the solar investment tax credit. According to SEIA, "As a result of the multi-year extension of the credit enacted in late-2015, solar prices have continued to fall while installation rates and technological efficiencies are continuing to climb. The ITC is nothing short of a tax policy success story and we expect this fact to continue to play out over the next several years," (4). The gains in technological efficiencies and the fall in solar prices can instead be attributed to the accomplishments of the integrated circuit industry. This flawed logic caused resources to be mis allocated from more valuable uses to photo voltaics. If that capital had instead been invested in other industries, it would provide better value for consumers.

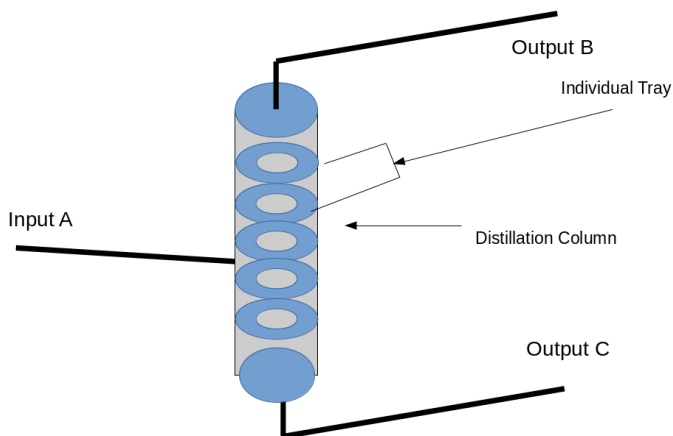
### **4. Better options given a correction to Swanson's Law**

A better option to the subsidies of solar infrastructure would have been to wait longer before the photo voltaic build-out. The past few decades of investments in solar industry should instead have been postponed. Even without the cumulative module shipments as shown by Swanson's Law, most of the declines in module price and technological efficiency would have occurred. As we approach the year 2020, projections had fore casted photo voltaics to become cost competitive relative to conventional energy sources. New findings indicate that the most recent cost reductions were non-repeatable reductions due to the one time effect of the dollar's strength and the effect of dumping.

### **Separations**

One of the key components linking the photo voltaic industry and integrated circuit industry is the similar way by which each unit separates silicon. Both Integrated Circuit (IC) and Photo Voltaic (PV) industries separate the silicon through separation process.

## Topic: Separations



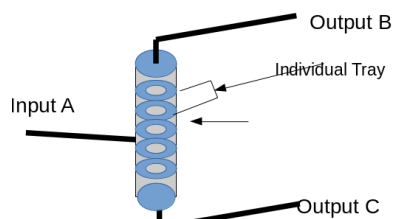
**Generic Distillation Column A** Figure 28.7

In chemical engineering a basic unit to conduct separation and purification is the distillation column. This can be represented by Generic Distillation Column A. The Figure 28.8 shows a generic distillation column which consists of a series of trays, the unit of separation. Alternatively, the column can be represented as a single column with continuous separation, as shown in Generic Separator Figure B.

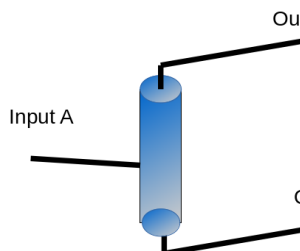
The Figure 28.9 shows a phase diagram. These phase diagrams illustrate the two models to consider: Continuous and discrete. A series of discrete separations represented by Generic Distillation Column A. These discrete separations are represented by the dotted line. The single continuous separation is represented by the solid line shown in the figure 28.9. This is the equivalent of Generic Separator Figure B.

For purposes of analyzing the photo voltaic and integrated circuit industries, this text will start with Generic Separator Figure B. This simplification is made knowing the limitations. This simplification should suffice for the next analysis show in Figure 29 and Figure 30.

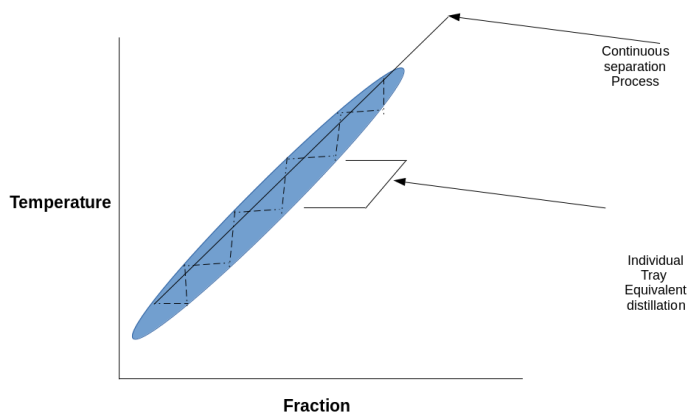
## Topic: Separations



**Generic Distillation Column A**



**Generic Separator Figure B**



**Distillation Phase Diagram**

## Silicon Manufacturing Process

# Separation In Silicon Manufacturing

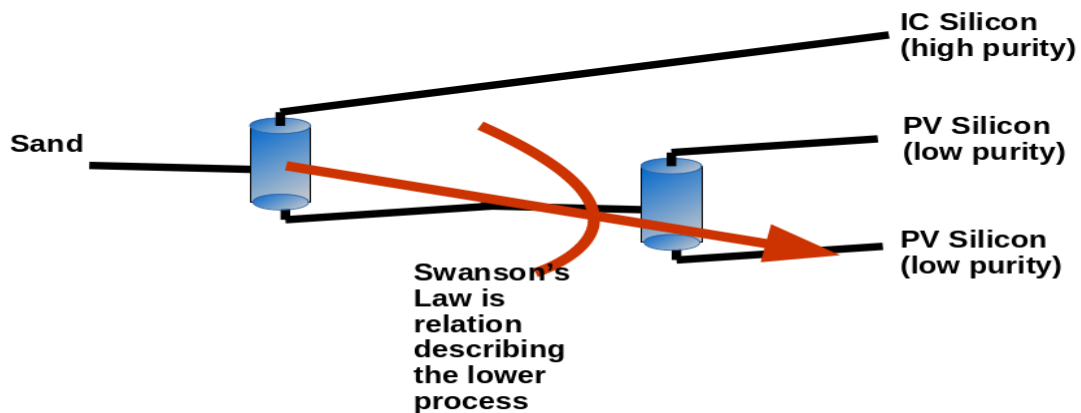


Figure 29

# Separation In Silicon Manufacturing

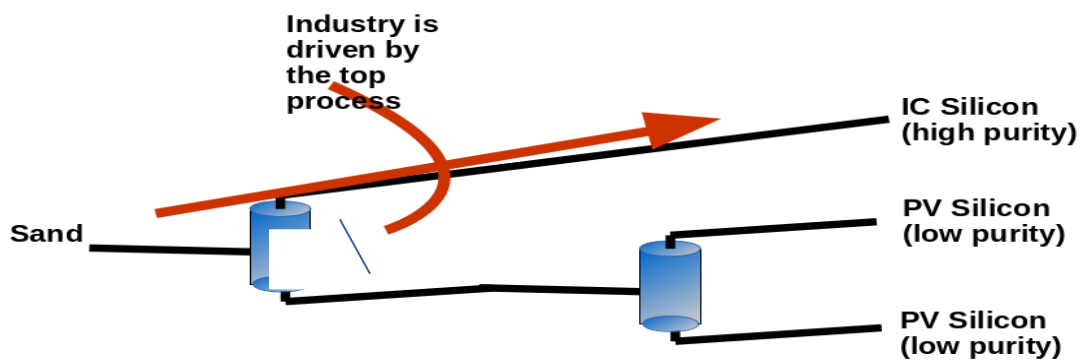


Figure 30

Comparison of IC and PV processes

- 1)  $V_{IC} \gg V_{PV}$
- 2)  $P_{IC} \gg P_{PV}$

Which leaves us with the process for integrated circuits as dominant process for silicon manufacturing. This holds for most of industry's history. where:

- 1)  $V_{IC}$  is volume of silicon for integrated circuits
- 2)  $V_{PV}$  is volume of silicon for photo voltaics (solar cells)
- 3)  $P_{IC}$  is price of silicon for integrated circuits
- 4)  $P_{PV}$  is price of silicon for photo voltaics (solar cells)

When evaluating projects which rely on government subsidies for a domestic infant industry, such as photo voltaics, try to screen for this type of flaw. The flaw here is falsely attributing cost curves for the subject industry (photo voltaics) to an exterior and more influential industry (integrated circuits). Here the relation between joint products can explain the correlation. For Swanson's Law correlation does not mean causation.

In the chart below you can see the wedge of energy cost differential for different sources of energy. The combined cycle was chosen as a point of reference due to its low cost of energy and low carbon impact relative to the traditional conventional sources of energy. The combined cycle is the grey component below the solar area, from 0 to 73. The wedge in black stripes represents the cost premium for solar energy relative to a combined cycle alternative.

As you can see from the chart below, the cost differential narrows over time. This reflects the gains in technological efficiency in solar energy as time progressed. According to the logic of subsidies and the domestic infant industry argument, the additional costs shown in black stripes will one day pay back.

The newly exposed flaw in Swanson's Law means that industry did not need to incur the losses in black stripes to get the benefits of lowered solar costs. Instead of the losing solar investments shown in the black stripes section of the chart, industry should have postponed solar investments. It would have been more economical for the solar industry to freeloader off the integrated circuit industry during the period 1990 to 2018.

Excess costs incurred by premature solar photo voltaic build out:

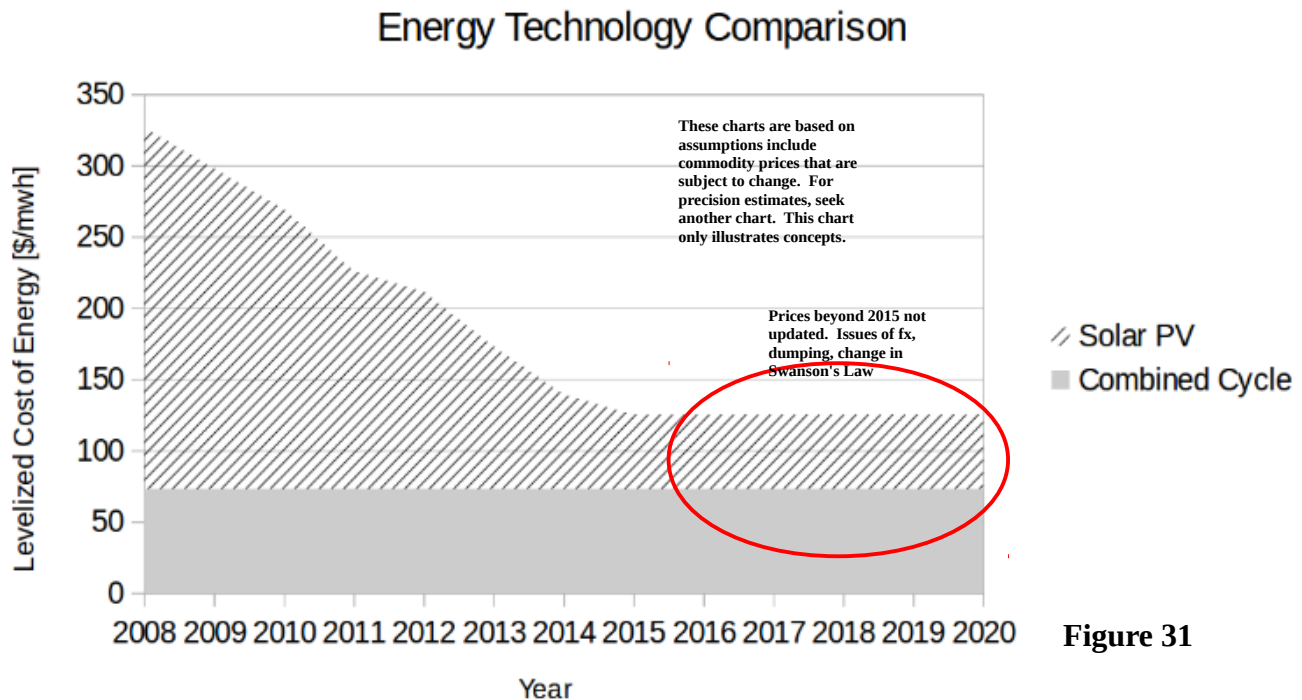


Figure 31

The area under the curve below illustrates the leveled cost of energy differential between solar energy and combined cycles. Combined cycles are chosen here because they are an alternative to solar energy. The cost of energy curves are extrapolated based on estimates from Wikipedia and Scientific American. The area in black stripes is the cost differential advantage of using combined cycles instead of solar photo voltaics.

It indicates the out of the money nature of solar photo voltaic projects. These out of the money projects were subsidized by government funds which would have been better placed elsewhere. Instead of solar photo voltaic industry build out, those funds could have been better utilized on research and development or to enable combined cycle build out.

**Citations:**

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## **SOLAR ENERGY: SWANSON'S LAW UNRAVELED 2**

### **Chapter Summary**

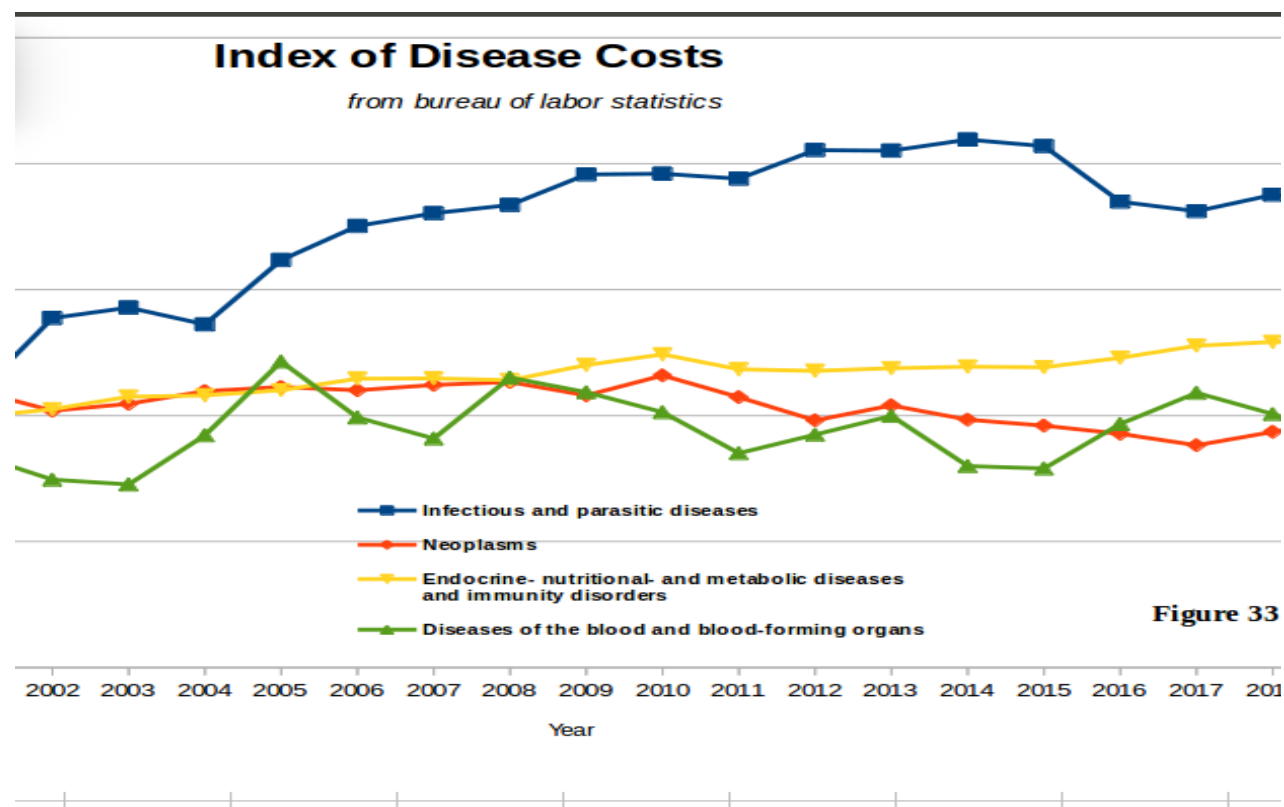
This chapter follows up on a prior chapter. It shows more info on how the learning curve Swanson's Law is following the integrated circuit. It considers a comparison to other industries, where the exponential trend stands out. It finally explains arguments for why these two curves are disconnected.

#### **Photo voltaics manufacturing vs. other manufacturing**

Now we have started to suggest that Swanson's Law Unraveled is a false relation. In order to illustrate that point even more, we must conduct a study and analysis of manufacturing industry cost curves and related trends. Industries to be studied as points of reference relative to photo voltaic industry include various price indexes, oil industry costs, auto industry costs, aircraft industry costs, space industry costs, and finally Moore's Law cost curves.

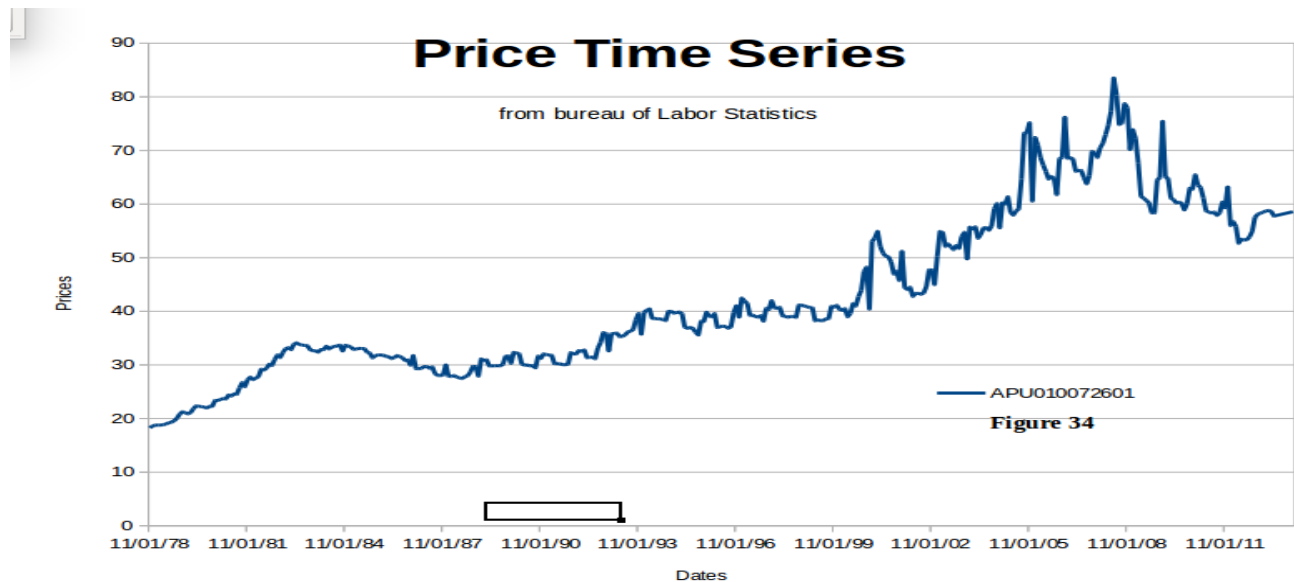
Various price indexes are used to show consumer product and service prices changes over time. From this, you can see changes in price for various health care treatments and other consumer products. These data sources illustrated by the next few charts in this chapter.

Another industry considered is the oil industry. Oil market price fluctuations follow a pseudo-random walk. Here there is no consistent trend over time. The supply and demand shocks occur in a mostly unpredictable way. Here the 1970s oil embargo was an unexpected shock to oil supply. The 2008 oil bubble collapse was a mostly unexpected decline due to macroeconomic losses. Although there have been some advances in cost structures and drilling over history, the alternative force of weather and geopolitical tension is more of a driver on short term price volatility than cost declines. Oil is a commodity following no consistent or reliable trend.



The next industry considered is auto industry. Auto manufacturing is a key industry more relevant in the United States than elsewhere. It is more relevant because Americans drive more than citizens of other nations.

Another industry considered is the aircraft industry. Since its initial inception, the market size of the aircraft industry has increased over time. It does not exhibit the strong exponential growth seen in photo voltaic or integrated circuits. The aircraft industry is cyclical and dependent on economic growth. Of course the technological capabilities of aircraft did expand, and peak / transition during the 1970s.



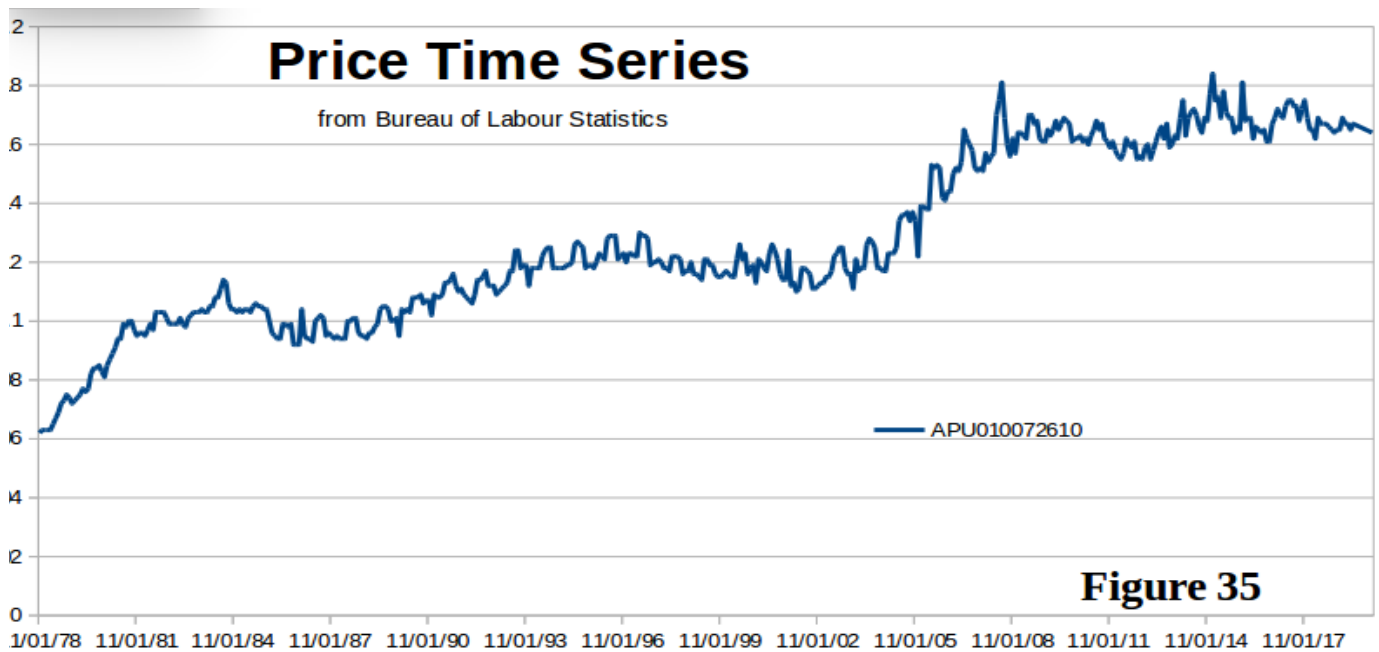
This can be seen in the speed of aircraft capability, their engine types, and the electronics/avionics capabilities of the aircraft. Starting in the early 1900s, the Wright brothers flew the first aircraft, with a propeller driven engine. Advances up to World War I enabled planes to expand to include multiple engines. As aircraft capabilities increased into World War II, engine sizes and reliability increased, along with ranges increases and altitude capabilities. World War II culminated with the advent of the jet engine used by German jet aircraft and primitive cruise missiles. Post World War II capabilities entered their final few decades of improvements with the increase in aircraft beyond the sound barrier and a fastest speed achievement of the SR-71 when the highest speed was achieved at Mach 3.

The 1970s saw the peak in aircraft capabilities. Here speeds peaked. New advances in aircraft capabilities focused on advancing avionics, radar capabilities, countermeasures, radar jamming and stealth capabilities. New delivery vehicles shifted the danger away from the pilot and collateral damage and toward cruise missiles, laser guided munitions, and other smart weapons. Here a trend for smarter weapons at technologies displaced the prior trend's need for speed, altitude, and size.

Much of the modern era's increased aircraft market share is driven by demand changes rather than cost structures. Costs of aircraft have only increased from what they were in the past. So that cost increase could not enable a growth in market share. But the increase in demand did pull up the market for aircraft. One trend feeding that weak exponential growth in aircraft market include the exponential nature in population growth. Another trend feeding that growth was market penetration from increased flight needs to fuel the trend in global trade expansion.

The space industry is a relevant industry to consider. In the space industry, you can see that technological advances increased the size and distance of human driven space capabilities up until the early 1970s. Following the 1970s, new trends sacrificed distance and human travel in a search for cheaper less impactful forms of space travel. The first voyage into space travel began in the 1960s when the Russians put the first satellite, Sputnik, into orbit. Later the first animal, a monkey named Albert, made his way into space. After two decades of space race, the lead shifted from Russians to Americans. Here you can see that Americans increased the distance of human flight from initial orbits in space to trips to the moon and back.

With the end of the Apollo era, a peak in technological advancement was reached. A bulge in space exploration spending peaked in the 1960s shortly before the moon landings began. The new trend after the 1970s shifted from extending human flight and feats of accomplishment to cost reduction. Here a space station sought to economize the cost of experiments in space living. Also, a space shuttle was created to reuse the space vehicle, a choice in the trade off that chose conservation over performance.



The final industry this chapter will consider as a point of reference is the semiconductor industry. The semiconductor industry was formed in the mid 1900s with the invention of the transistor. Here an old device, the vacuum tube was replaced with a more advanced device, the transistor. The vacuum tube had previously been the basic unit which made up primitive computers dating back before World War II. These primitive computers could be used for code breaking and various other applications. They were typically available to large corporations and government organizations, but their size and cost made them beyond the scope of use for ordinary Americans.

The advent of the transistor and integrated circuit replaced the vacuum tube with a more reliable substitute. Here the transistor allowed the miniaturization of the logic underlying computers. The silicon based circuits were not only smaller, but more reliable. A cost curve called Moore's law enabled strong exponential growth to develop. Increases in the wafer's size, reduction in transistor size, and other manufacturing improvements enabled an exponential increase in computer hardware performance.

The market size increase of the transistor and computer hardware experienced exponential growth. The growth was driven by cost pull phenomenon. Here rapid declines in cost of production lowered the hardware's price. Lowered price enabled wider markets for the computer hardware as more businesses could find a use for the computer use and hardware. In this way, lowered price lead the cost pull driven increase in computer availability.

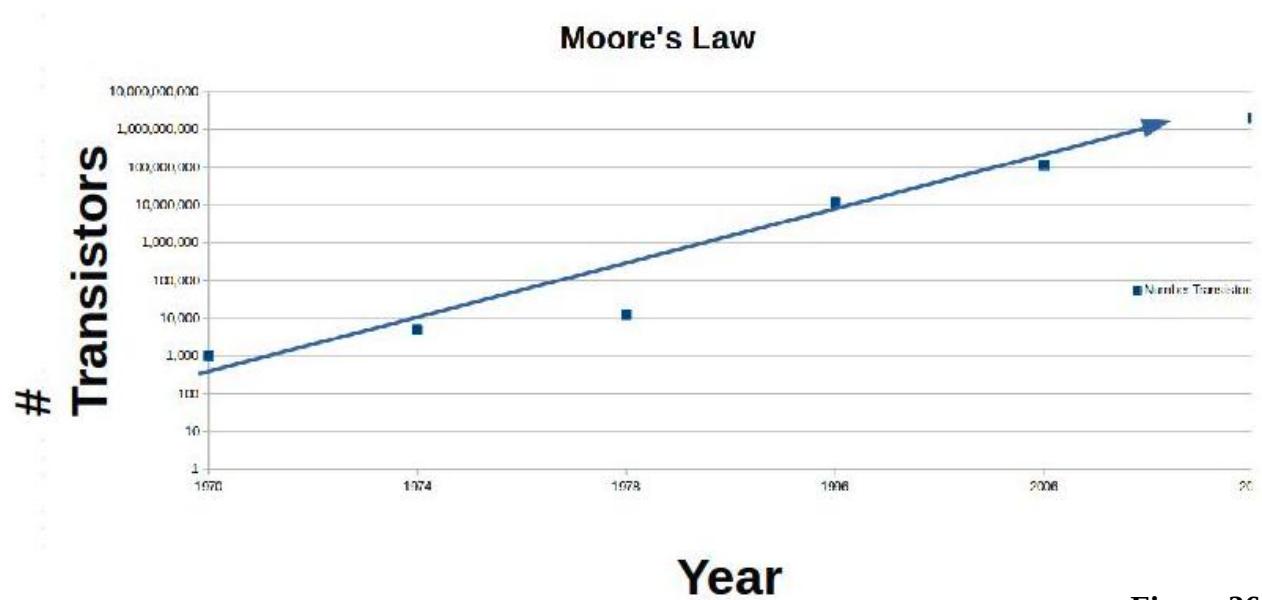


Figure 36

### Photo voltaic Drivers Explained

Above we have explored how price and market trends drove growth in manufactured goods. Across different industries and types, you can see how trends have caused certain types of industries to perform according to the fundamentals of the situation. Now that we understand the fundamentals of industry market and price trends, we can apply that understanding to the analysis of our main focus: the photo voltaic industry.

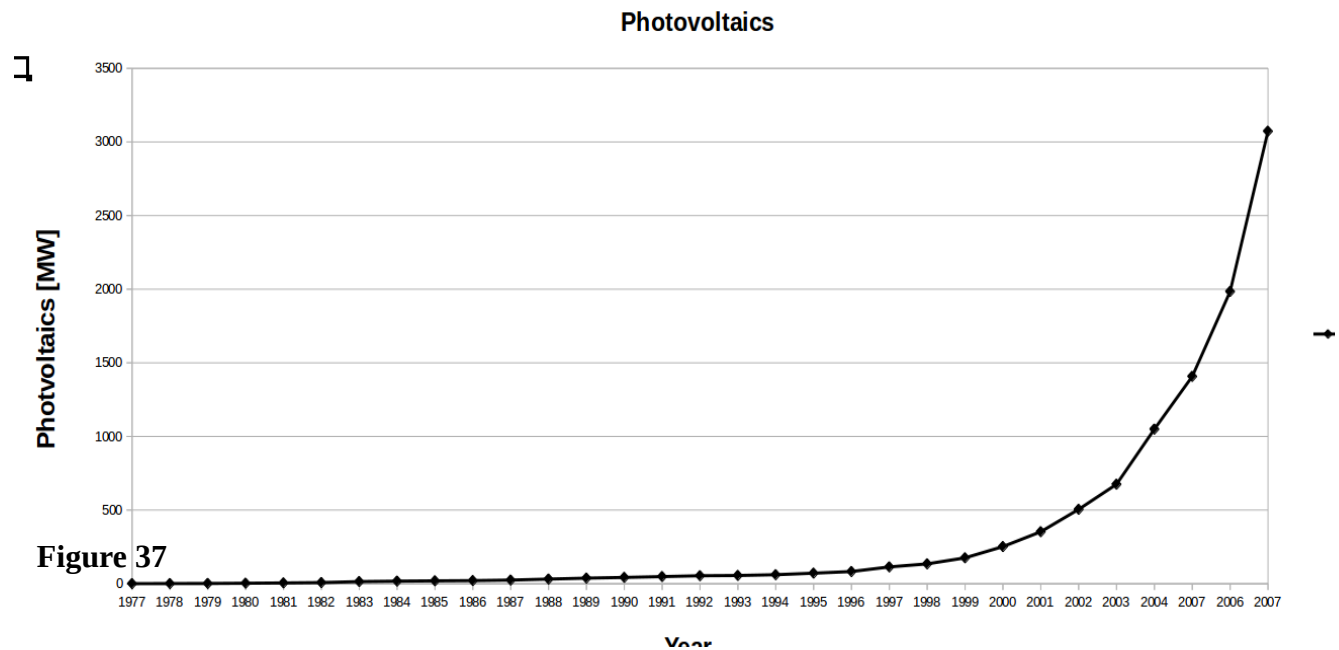


Figure 37

The photo voltaic industry exhibits strong exponential growth. The industry's growth drives downward the price of photo voltaics. And the industry's growth drives up the strong exponential growth in market share of photo voltaics. The types of exponential growth here is very strong relative to most other industries. Its pace is far beyond the pace an observer would expect from underlying population growth or demographic shifts. These strong exponential growth patterns are only observed in the comparable integrated circuit industry which exhibits Moore's Law. The market share growth is driven by cost deflation. Here a rapid decline in price enables more consumers to afford the product.

Initial appearance quickly suggests that there is a relationship between integrated circuits, governed by Moore's Law, and that of photo voltaics, governed by Swanson's Law.

An important point to note here is what drives the growth of the industry? The driver behind the growth of the industry is an important point of contention because it has implication for government policy in regulation of the industry. If the decline in the cost of photo voltaics is driven by changes within the photo voltaic industry, then that would strengthen the argument for government subsidies during the industry's infant stages. If the decline in cost of photo voltaics is driven by changes exterior to the photo voltaic industry, that would weaken the need for government subsidies during the industry's infant stages.

Deeper investigation into the similar origin in manufacturing of the photo voltaics and integrated circuits suggest the two are joint products. This means that the two types of silicon are created in combination, in a process related, sometimes connected in series, sometimes in a more separate way. In most of the history of photo voltaics, both the volume and price of integrated circuit grade silicon were much higher than the comparable traits of photo voltaics. Those increased revenues of photo voltaics suggest a higher status of integrated circuits in driving the manufacturing process of photo voltaics. In other words, photo voltaic industry follows the integrated circuit industry.

Recent trends show that recently the size of the photo voltaic market is beginning to surpass that of integrated circuits. So the driver behind this industry may change going forward. And therefore it is possible that photo voltaics may graduate to a higher status relative to their integrated circuit peers. And that increased relevance would make photo voltaics volume too substantial to freeload any longer off their integrated circuit counterpart. So the trend in Swanson's Law is possibly going to end. In order to more fully understand these drives, consider the infant industry argument in both domestic and original versions. It is through the application of those two arguments, in coordination with the fundamentals explained in the section above, which give us tax policy guidance.

The type of industry photo voltaic would be classified as is domestic infant industry, according to my definitions. The natural state of competition faced here is the competition of photo voltaics, as the infant, against incumbents, mostly domestic in the United States. A question the government should ask itself is: Does this industry's technological advancement depend on government subsidies? If other industries, such as the integrated circuit industry, can subsidize photo voltaics instead, that opens up the option for government policy to avoid subsidizing photo voltaics. Our evaluation in this case is that photo voltaics can get to break even by freeloading off the integrated circuit industry.

### **Types of Infant Industry Arguments**

Two types of classification can be used to guide our understanding of how government subsidies should apply to our industries. During the process of economic policy, government should consider the type of infant industry as a guide to determine if industry qualifies for tax subsidies. The two types of industry to consider here are 1) original infant industry, (which has been defined externally) and 2) domestic infant industry (which I define for this book).

The original infant industry argument assumes that a domestic industry is in an infant state. That domestic infant industry must compete with the industry of other countries. In certain cases a

government should subsidize these industry if 1) in the future the industry will be able to stand on its own feet, 2) subsidies are needed to compete and 3) future positive externalities are expected to exist.

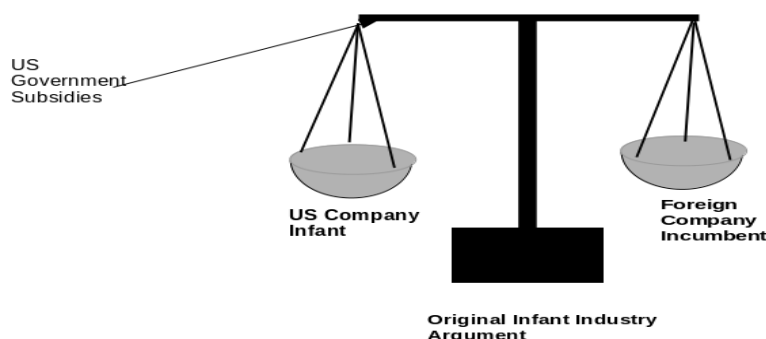


**Figure 38**

The domestic infant industry argument has been defined for this book. As a modified form of the original infant industry argument, it adjusts for new realities. While original infant industry argument focuses on defining the competition between on industry in the domestic country (US photo voltaics) and competitors in other countries (International photo voltaics), the domestic infant industry argument redefines the competition as a domestic infant industry (photo voltaics) against domestic incumbents (oil, natural gas, coal).

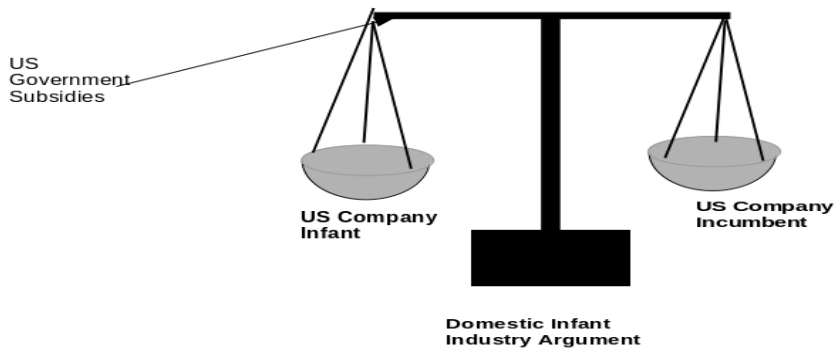
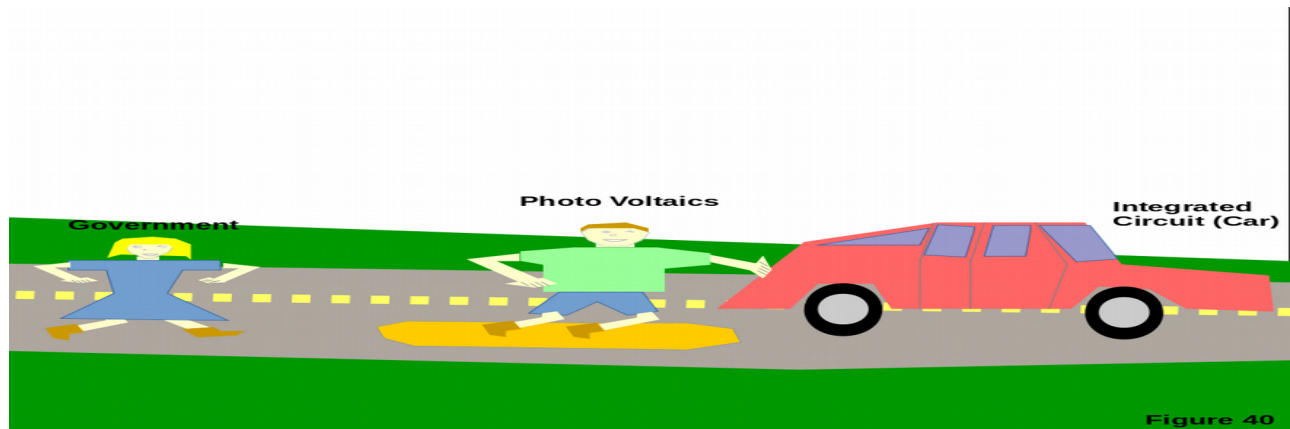


**Figure 39**

In order to apply these tests for domestic infant industry to the situation of photo voltaics, we consider: the following tests: 1) in the future the industry will be able to stand on its own feet, 2) subsidies are needed to compete and 3) future positive externalities are expected to exist. The first test suggests maybe, the industry will possibly be able to stand on its own two feet, possibly it will flat line as more costly than conventional sources. The second test suggests that no, subsidies are not needed to become competitive, because increases in industry competitiveness are actually driven by an exterior factor, the integrated circuit industry. The third test suggests that maybe future positive externalities will exist for carbon free energy relative to carbon intensive alternatives of coal and natural gas. The answer to these three tests suggests a weakened argument for subsidies, and that government policy should not use subsidies. The photo voltaic industry should wait and freeload off the integrated circuit industry's advances until the costs of photo voltaics have come down to competitive levels. The continuation of the cost reducing trend in Swanson's Law may not continue much longer.

In order to better illustrate the arguments, I suggest an analogy from a cartoon I have drawn. In this example, the boy riding on his skateboard is like the photo voltaic industry. The car which he holds onto, in order to hitch a ride, is the integrated circuit industry. The girl, his sister, is like the government. But the boy (photo voltaics) does not need his sister's (government's) push, because he can freeload off the car (integrated circuit).



In another example, the boy is like the photo voltaic industry. The hill he is coasting down is the integrated circuit industry. His sister is the government. The boy (photo voltaics) does not need his sister's (government's) push, because he can coast off the energy built up in the hill upon which he stands (Integrated Circuit).

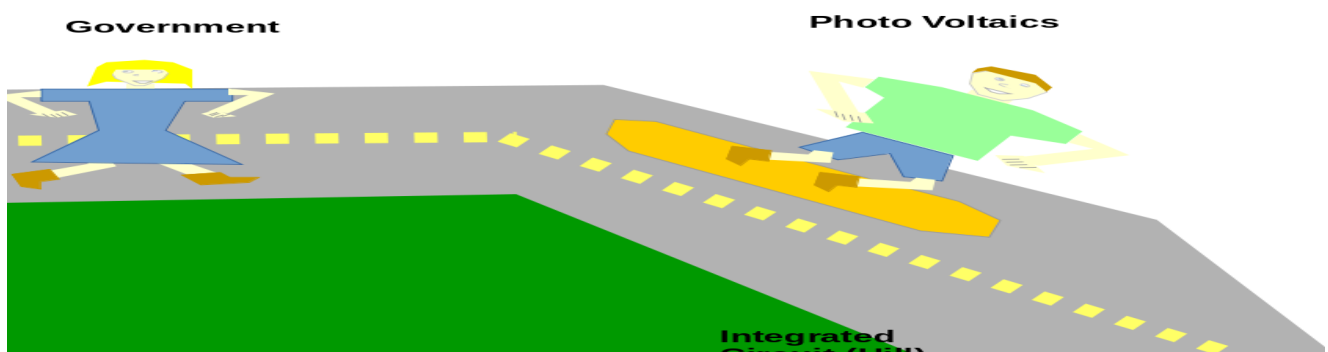
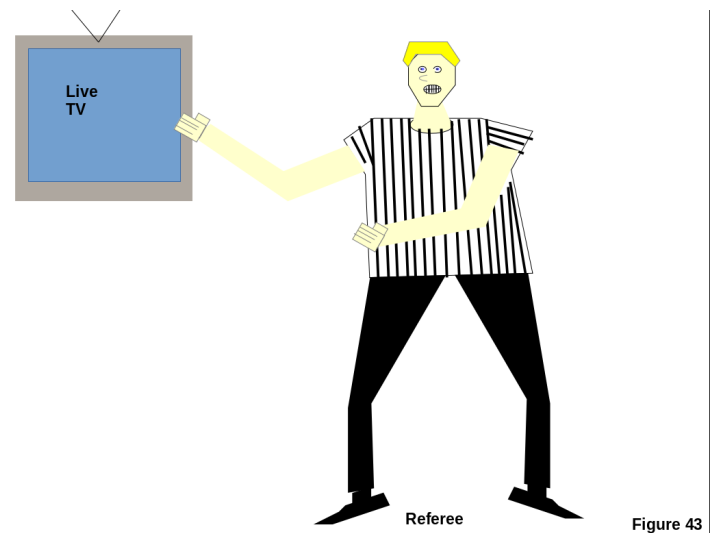
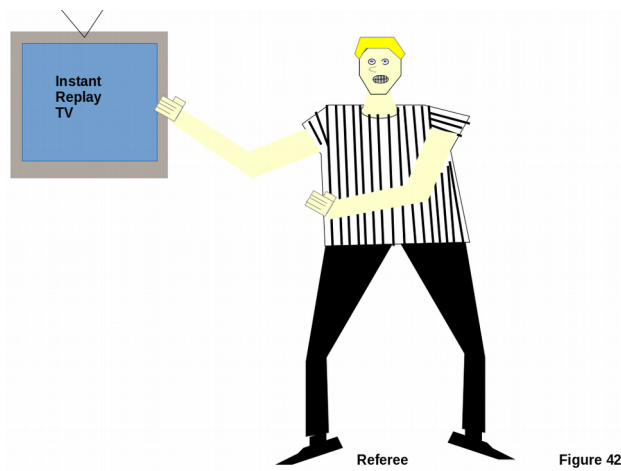


Figure 41

Examples of past industries show the use of infant industry arguments. Here we can see that mercantilist approaches of the past enabled infant industries to grow under government support. Consideration of examples like these may offer cases to study for future government and industrial cooperation. In the past, the British government subsidized its wool industry as an infant. Later, they emerged as the dominant industry. Also, the Spanish government funded expeditions to explore the new world. This led to initial Spanish dominance in the race to the new world.

In the example below, the author of this book is like a referee. The participant companies are like players in the game. By writing this book about the history of industry, he is like a referee narrating on instant replay.



In the example above, the author of the next book is like a referee. The participant companies are like players in the game. By writing another book in the future about industry expansion, he will be a referee narrating on live TV.

### Price drivers 2015

During the time period 2015 to 2016, price declines in Photo voltaics experienced a temporary decline. The decline could be attributed to recent strength in the US Dollar, which began in 2015. That decline in solar prices reflects the changes in foreign exchange which are not repeatable. For that reason, consider the forecasts for continued photo voltaic price declines to be overly optimistic. Consider it a more realistic possibility that photo voltaics will have a greater risk of delay reaching economic viability. With slow downs in Moore's Law as well, there will be potential for reduction in Swanson's Law's capability as well.

### Arguments: Swanson's Law Follows

Swanson's Law is a cost curve for reduction in price in the photo voltaic industry. It is likely that most of the reduction in costs can be attributed to the relation of as joint product with the

integrated circuit industry. Both industries share the same process for purifying silicon. For that reason, poly-silicon is the natural byproduct of less pure silicon relative to the integrated circuit silicon.

### **1) Coincidence of Two Exponential Laws**

One factor which initially suggests the relation between the integrated circuit industry and the photo voltaic industry is the similarity in cost curves. Moore's law shows a strong exponential trend in the cost curves where prices move downward. The same sort of strong exponential decline in cost can be seen in photo voltaic industry. The uniqueness of that exponential trend can be seen when its compared to the other manufacturing industries shown above. When we consider the other curves of manufacturing industries shown above, then the exponential nature of integrated circuits and photo voltaic stand out from most other manufacturing industries. This isolation of these two curves relative to most other manufacturing industries suggests the uniqueness of exponential trend in manufacturing photo voltaic and integrated circuits. These observations suggest they are related.

### **2) Moore's Law and Component Drivers**

The effect of Moore's law can be seen in the exponential decline in transistor prices over time. Components which drive this down are increases in wafer size, new materials, and decreasing size in transistors. These drivers enable the cost per transistor to decline consistently over time.

A batch process is used to process wafers across the many steps of the semiconductor industry. Larger wafer sizes make better use of the batch process of the semiconductor equipment. Declining transistor sizes enable higher frequencies in the computer clock cycles for cpus created by the semiconductor industry. Smaller dimensions per transistor enable more transistors per wafer. New materials enable photo-lithography equipment to operate at smaller wavelengths necessary for compressed transistor sizes.

### **3) Cost curves compared**

The cost curve for Moore's Law is exponential. The rate was initially to double the number of transistors every two years. Swanson's Law also has an exponential trend, but at a lower rate than the exponential trend exhibited by Moore's Law. The lower rate for Swanson's Law can be attributed to the fact that fewer cost reducing factors are at play. While integrated circuit's rate of decline benefits increased die sizes, smaller transistors, and better materials, photo voltaics fewer advantages to explain its rate of decline. Both processes share the Siemens processes for refining silicon into ingots. It is the shared cost reduction of this silicon manufacturing unit which drives the similarity in exponential rate of decline costs for both industries.

## **Curves to Optimize: Levelized cost of Energy**

### **1) Time and Cost, by Energy Type**

The chart shown in the prior chapter shows an expectation of decline in future costs for the price of various sorts of energy. An important point of reference to consider is that of the combined cycle. The combined cycle is a generic and relatively modern kind of gas fired power generation unit. It serves as a good point of reference, because in the lower carbon world of the future, combined cycles will survive carbon restrictions better than the other conventional types of fossil fuel driven generation. It is important for solar to get under the cost of combined cycles to enable it to stand on its own two feet.

The farther into the future the chart goes, the less certainty there is about solar prices. As you

can see from the chart, photo voltaic prices do not really decline. This book has not really prepared any forecast of long-dated photo voltaic price declines. For that reason, do not read deep meaning into the forward extrapolated price curves. The area under the curve below illustrates the leveled cost of energy differential between solar energy and combined cycles. Combined cycles are chosen here because they are an alternative to solar energy. The cost of energy curves are extrapolated based on estimates from Wikipedia and Scientific American. The area in black stripes is the cost differential advantage of using combined cycles instead of solar photo voltaics.

## 2) Curve Shifts by Subsidy: Carbon Tax and Bond Subsidy

Below are charts which illustrate the effect of carbon tax and bond subsidy. These are considered because of their different impact on the merit order of combined cycles, photo voltaics, and coal based power generation. They have implications for the efficiency that can be achieved.

The charts below shows the impact of different carbon restriction types on power generation. Power generation was chosen for this example because it is the sector of energy which has most immediate solutions in terms of carbon reduction. Fuels considered are coal, natural gas, and solar. Their carbon-intensiveness is ordered from most carbon intensive (coal) to least carbon intensive (solar).

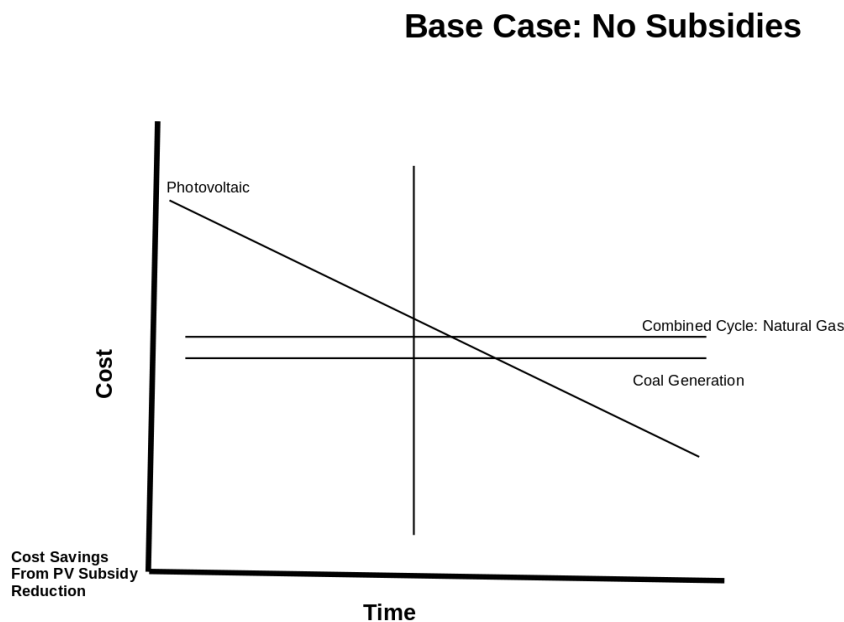


**Figure 44**

The first chart shows the status quo, with no carbon restrictions on the power sector. The vertical lines shows the demand for electricity. Two horizontal and one downward sloping lines are designed to show the relative prices of each fuel type, using current day price levels. The top downward sloping line is the supply curve for solar energy. The middle horizontal line is the supply curve for combined cycle gas based energy. The third and lowest horizontal line is the supply curve for coal based power generation. The relative value of each fuel type reflects their relative order within the power stack.

### With solar bond subsidies

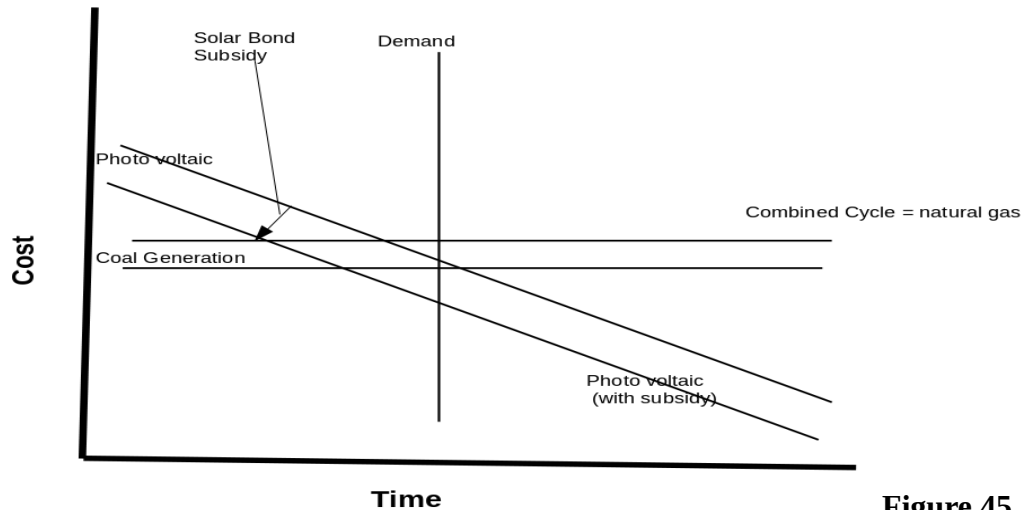
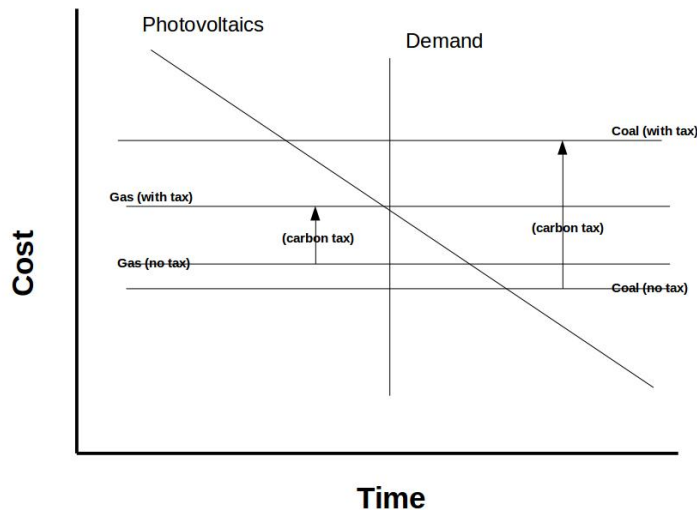


Figure 45

The second chart is a modified version of the first chart, which additional subsidies added for solar bonds. The effect of solar bonds is to reduce the cost of capital for solar projects through lower interest rates on the bonds. When that lowered cost of capital reaches solar projects, it passes through to the price of solar power. The arrow shows the shift in solar power curve. Here you can see the impact of this type of carbon regulation fails to impact the relative merit order of coal and gas generation.

The third chart is a modified version of the first chart, which has added carbon taxes. Here the carbon tax raises the price of coal power supply by a large amount (long arrow) and it also raises the price of natural gas supplied power by a small amount (short arrow). These final chart shows the impact of carbon taxes. Here an advantage exists, because the carbon tax shows correct advantage to natural gas over coal, and to solar over natural gas. A carbon tax is the superior form of energy subsidy.

**Figure 46**



### **Future of photo voltaics**

The charts of Swanson's Law Unraveled show cost comparisons of different types of power. After the year 2015 the costs are left level, and extrapolated forward. That chart, Energy Technology Comparison, holds constant the price of solar energy after 2015. This constantly held price does not really reflect the price expectation or reporting. It reflects uncertainty from dumping effects and foreign exchange rates, and potential breakdown in Swanson's Law.

In order to update that book preview, a few considerations are to be evaluated. The first consideration is that the actualized prices of industry have been updated and do in fact show lower prices actualized after 2015, which need to be updated for that chart. The second consideration is the quality of price reductions in the past few years. Finally, the quality of those price reductions and underlying drivers in the process will be considered to form a future expectation for photo voltaics.

The first consideration to be considered is the actualization of prices since 2015. This information is to inform an update of the chart shown in Swanson's Law Unraveled, the first preview chapter. The chart considered is the chart Energy Technology Comparison. This chart shows the prices updated for up to 2015. After 2015, the prices of photo voltaics are not updated. The reason for that lack of update are twofold. First the prices are off because of dumping. Second, the prices are off because of the effect of foreign exchange effects.

First and foremost the prices during the mid 2010s are facing circumstances not driven by Swanson's Law or any repeatable market fundamentals. The prices are affected by the unrepeatable issue of dumping from countries other than the United States. The effect of this dumping may have caused the prices which actualized during the mid 2010s to reflect off market prices. What this means is that the prices were so low that industry could not justify the costs to produce photo voltaics at the price levels during that period of time.

The second problem with price's decline during this time period was the issue of large changes to foreign exchange rates. Foreign exchange rates declined so that the US dollar became stronger. What this means is that the strong dollar enabled us to buy solar from overseas companies at steeply discounted prices. The steep price declines seen after 2015 were not the sort of price declines that

would be expected to be repeatable in the future. It is not likely that such large increases in the US dollar can be expected to occur indefinitely in the future. For that reason, photo voltaic price declines during the period following 2015 are suspect.

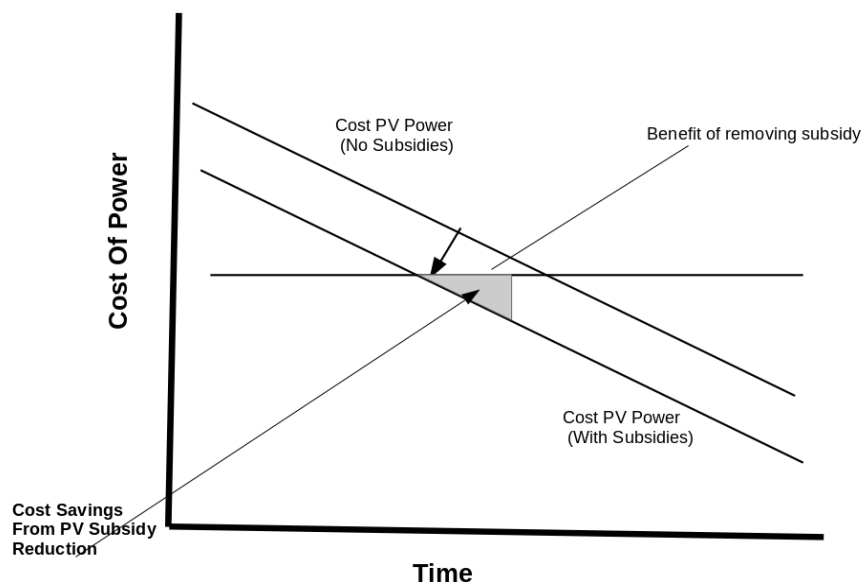
The implications of the two issues raised above, combined with fundamental issues underlying Swanson's Law, suggest problems for Swanson's Law going forward. The recent past of price reductions in Swanson's Law have been shown to be unrelated to photo voltaic industry dynamics. This suggests the recent past of photo voltaic price declines will be difficult to repeat. Underlying mechanics of Swanson's Law, which make it adept at freeloading off the integrated circuit industry, show signs of future failure. It unlikely that the underlying mechanics of Swanson's Law will be repeatable in the future. Based on the past unrepeatable price declines and changes in the underlying mechanics of Swanson's Law, expect the price declines of photo voltaics in the past are unlikely to continue going forward.

### New Thin Films potential

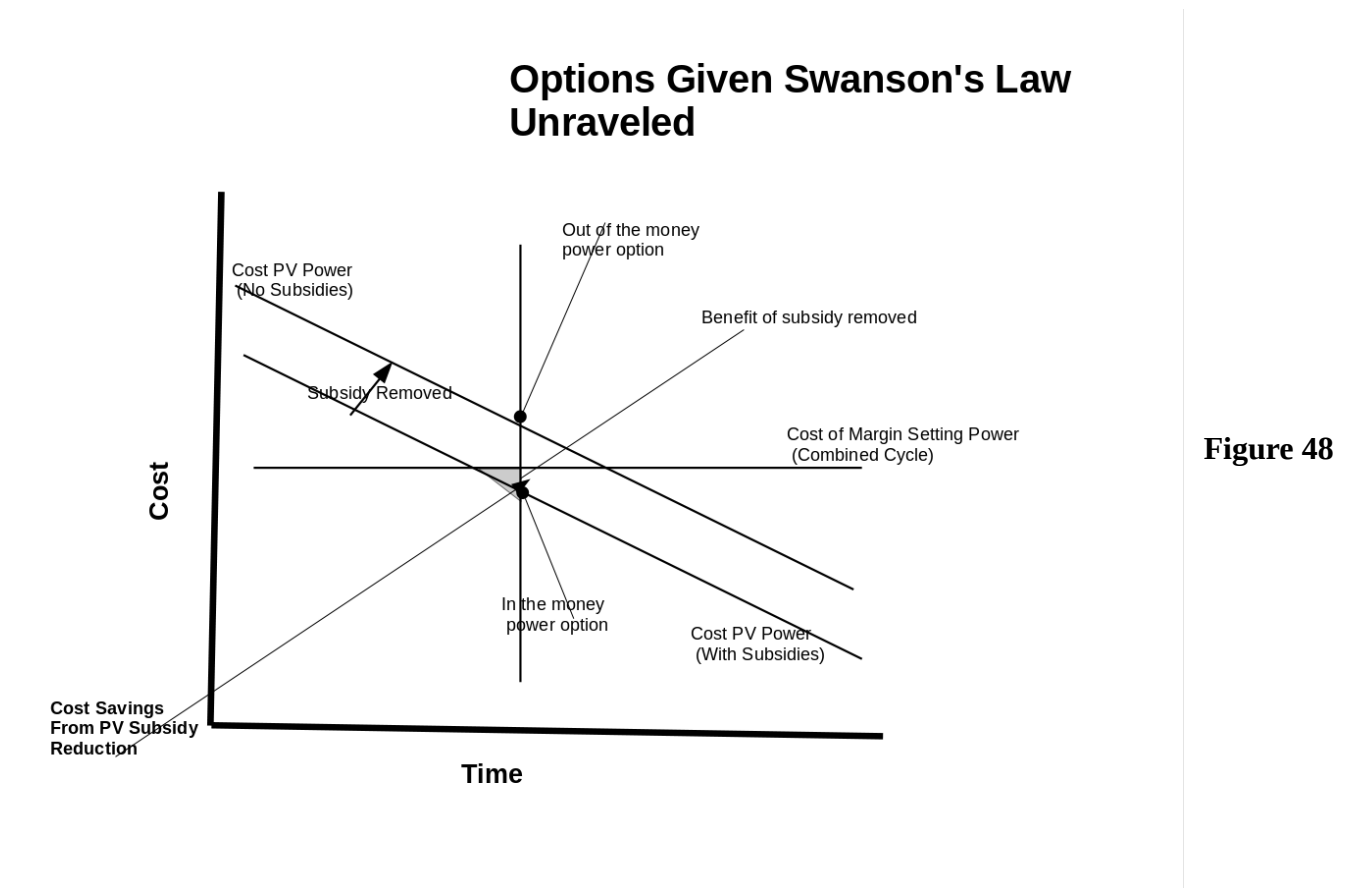
One of the newer technologies of photo voltaics are thin films. Thin films have some advantages over other types of solar. This includes being easier to install. They are also less expensive. The downsides include they are less efficient than their counterparts. During the 1990s, the thin films displaced conventional solar photo voltaics. After their peak of market share during the mid 1990s, thin films market share growth gradually eroded. Since then, there have been several new kinds of thin films. None have yet to show any substantial gains to repeat their success in the mid 1990s. Certain sources claim that thin films to have great efficiency gains in the future which will rival combined cycle alternatives. Yellow Dog Books expects that the optimistic thin film cost reductions are not likely to occur in the optimistic time-frame suggested.

Defects In Industry

Figure 47



The chart above shows defects in industry. It relates the cost of power over time to the different scenarios of subsidy. A shaded area illustrates value savings we could incur if we postpone photo voltaics and solar technology.



The above chart shows the impact of Swanson's Law Unraveled, applied to the photo voltaic industry. The vertical axis shows the cost of energy. The horizontal axis shows time. The horizontal line on the chart illustrates the cost of natural gas fueled power generation. Two downward sloping lines indicate cost of solar energy both before and after subsidies have been applied. A measure is shown for the impact of the subsidy. Finally, a vertical line reflects where we are today. Two points of intersection reflect the two states of solar: economical (in the money) with subsidies, and uneconomical (out of the money) without subsidies.

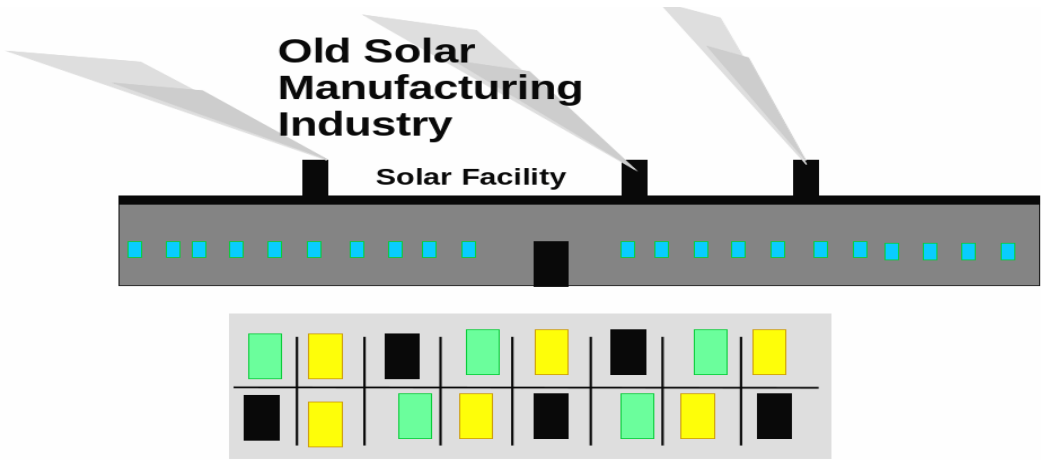


Figure 49

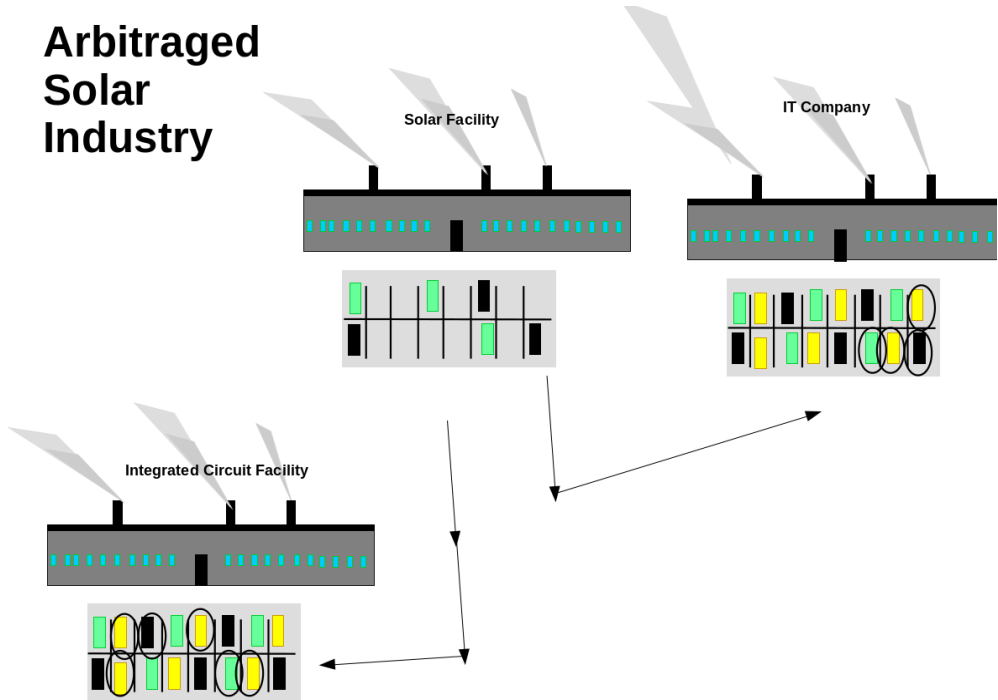


Figure 50

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**Citations:**

1) Time Series of various commodities and products. Retrieved 20190803, from <https://download.bls.gov/pub/time.series/cu/>. . . .

## **Arbitrage the Industry**

Above you can see in the two diagrams there is a way to better illustrate the alternative configurations for industry. Here the original situation shows that solar manufacturing industry employs resources in currently out of the money industries. Once Swanson's Law Unraveled has shown that delay in solar build-out is a better option, changes to industry should reallocate labor. The second diagram shows that solar manufacturing resources should make their way to other better uses of those resources.

## INDEX Summary

The Index contains a story about the book's writing and an example of past versions of the book. The story explains how difficulty was encountered getting acceptance for the book. Its past version shows how it has changed over time.

### A) Story of Changes

In 2007 I completed my BS degree in Chemical Engineering at the University of Texas at Austin. Near the end of my studies in Austin, I expressed an idea to work on renewables. I took a detour to the commodities markets and an attempt at a startup in the internet software industry. A decade later I took a stab at analyzing the renewable energy industry after more than a decade of distraction. I set off to cover the renewable energy industry, beginning with photo voltaics.

The content of this book has been submitted and changed and resubmitted and since late July 2018. Its original form was a manuscript entitled Swanson's Law Unraveled. It served as a counter argument to the Economist Argument from 2012 which named a cost curve "Swanson's Law." It was originally submitted to Progress in Photo voltaics: Research Applications. It was rejected since it did not fit the scope in of their journal. Of course Progress in Photo voltaics: Research Applications had accepted Swanson's original research paper since its exponential cost reduction curve would advance the industry. Other trouble encountered was strange and incorrect suggestions from a journal on how to title charts and figures.

After the initial rejection, another attempt to submit the manuscript took the form of a Book Titled "Market Inefficiencies". Here the book included the content of the manuscript Swanson's Law Unraveled, in addition to chapters on software, semiconductors, Electrical Industry, and changes in Economic Growth rates, Intellectual Property, and operating system.

The book version was marketed on IndieGoGo. Its advertisements were through Linked-in, Facebook, and Linked-in. Here the book's concept, with sample chapters, was presented. A month passed, but few viewers arrived. No interest was found in funding the book. The original version was slated to be 200 to 300 pages in length. The end result of no funding forced me to cut the length of the book from 200 to 300 pages down to 50 to 100. If deeper and more certain analysis is sought, it could

be created in exchange for funding.

The reason for my lack of initial success is partially known. The journals I had approached did not seem to want my manuscript to burst their bubble. My approach for a highly technical engineering type book did not fit well in this channel. Finally, some insults I made to various groups may have had an impact on my distribution.

This book exploits an inefficiency of its own in writing about the photo voltaic industry. Of course it takes advantage of past information to make suggestions of better use of resources. Those conditions are unrealistic to the reality faced by industry participants, who must make the decisions without the benefit of perfect hindsight. In this the regulators, legislators, solar company and industry planners are facing a more challenging environment than I did. Maybe my next book will argue for industrial decisions ahead of time to make it A) more of a fair fight and B) a more valuable set of future analysis, insight, and advise.

Most ordinary readers do not seek deeply technical books on their own. Engineering departments typically have requirements written by professors that students must meet. For deep technical books such as this, a better market for this sort of book may be engineering departments and libraries rather than the general populace found on IndieGoGo.

Deeper investigation for this version of the book have made improvements to the original proposal on IndieGoGo. The original proposal labeled photo voltaics as a waste of the integrated circuit industry. Deeper investigation merits a slightly different designation. Processes enable the conversion of waste streams into useful feed-stocks. It is true that photo voltaic silicon is not up to standards for integrated circuits. However, the use of recycling allows photo voltaic to serve as a feedstock, useful to integrated circuits once it has been updated.

Further investigation also uncovered downside to the trend of Swanson's Law. Earlier papers showed Swanson's Law as a continual trend. New findings in the fundamentals and recent price drivers suggest that the ability to continue cost reductions into the future is suspect. Recent declines may be due to dumping and uneconomic activity. A strengthening of the dollar also artificially reduced photo voltaic prices as observed by consumers in the United States. Future expectations of price declines may not be as optimistic as they were in the past. The new pessimistic view point has been expressed in this edition of the book, updated from the initial IndieGoGo proposal.

IndieGoGo had bad business practices from the standpoint of a user. They were not consistent in their use application of terms. Even though I did not agree to their changes, they made changes to my proposal that screwed it up. They changed my writings in ways the reduced their use and value. They removed disclaimers that would change the meaning of Swanson's Law Unraveled. For this reason, I recommend users exercise caution when doing business with IndieGoGo.

This book is owned solely by Yellow Dog Books LLC. The proposal included a false label of Yellow Dog News LLC. It is suspected that they were wrongly inserted by hackers Yellow Dog News LLC into the initial proposal.

Initial adversity only emboldened my resolve to get out my manuscript. Lack of funding forced me to shorten the book. But I expect the shortened version, in the main segment of this book, will provide useful insight to readers. To see the original proposed book, look at the items in Appendix II. I considered retitling it: Energy Infrastructure Transitions: Photo voltaic Industries. This new title reflected the limited scope of the new book.

The first attempt to copyright and public this book in early November 2018 was delayed. Hackers messed with the status of Yellow Dog Books LLC and the books figures and text. Hackers added a feature where “And, “ was perpended to many sentences. And a few other words were inserted. A few other figures were inserted. This second version has been added on December 10, 2018, before any books were sold and before the original copyright could be completed.

### **Revisions: Q3 2019**

The Q3 2019 edition has several revisions. One was to replace crude stick figures with better illustrations. This improvement was designed to bring the book in line with publishing industry standards. As suggested by book publishers, it is expected to make the book more suitable to non self publishing companies.

Also, changes were made to separations as illustrated for the topic of Swanson's Law Unraveled. These changes should simplify otherwise complicated diagrams. They also add background to connect the concepts to chemical engineering knowledge.

More data was analyzed, separately from the data in the chapter Swanson's Law Unraveled 2. This new set of data suggests that most commodities and consumer products within the economy are in line with the arguments for this chapter. This new dataset confirms that the strong exponential nature of costs for integrated circuits and photo voltaics makes them unique among the majority of the non-strong-exponential consumer products made within our economy.

The choice was made to replace old data with the new data in this 3rd edition of the book. The value of new data could improve the chapter with a more consistent basis for data analysis. Limitations of data use and access prevent further publication of data analysis to support Swanson's Law Unraveled 2. It should suffice to say, the author's initial conclusion became stronger after more thorough data analysis was conducted.

### **Revisions: October 2019**

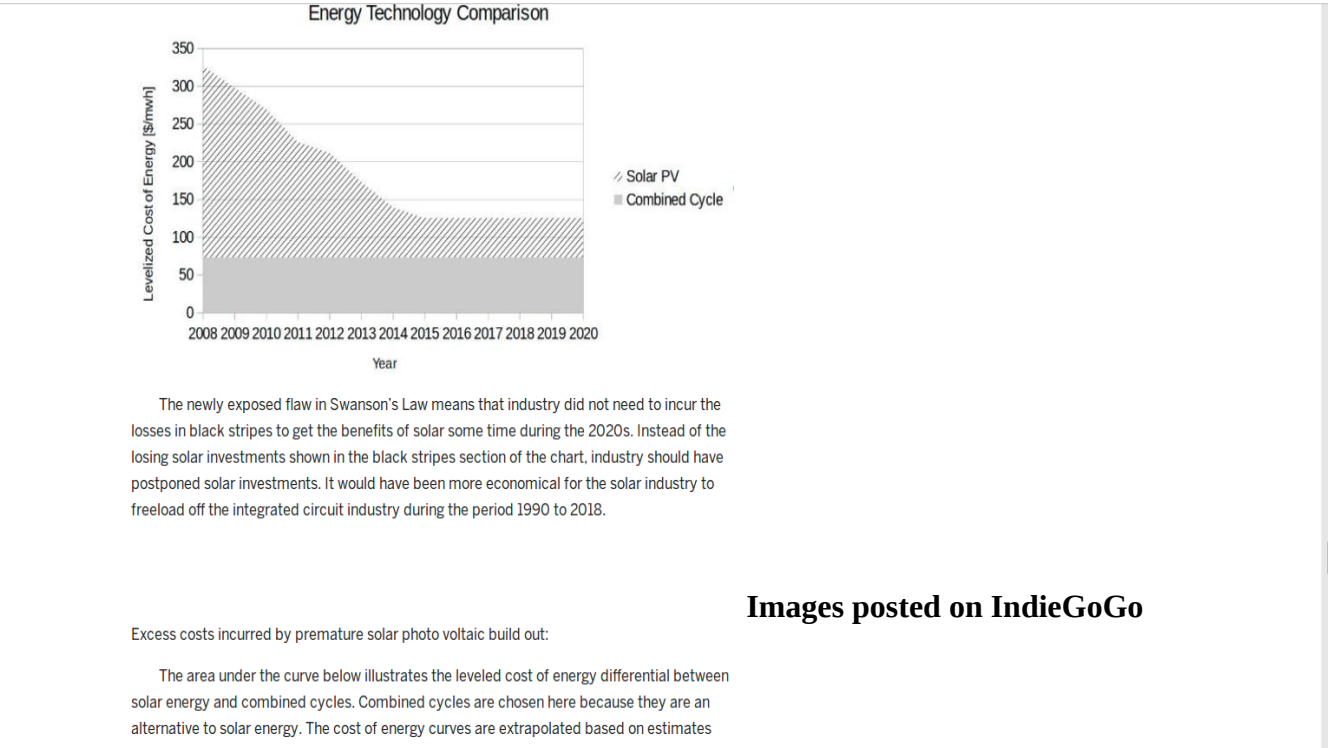
notes: these corrections reflect fixes in October 2019. During the upload to archive.org, hacks adjusted a few words in the 3rd edition. This 3rd edition B fixes those hacks. Its not guaranteed the hacks were fixed, only the most easy to identify. The hackers were not supposed to be in my book.

- 1) some figures lost quality as translated into pdf and archive.org's format.
- 2) page 30: this paragraph was probably moved and changed a bit. Paragraph starting with "Our industries"
- 3) page 31: The sentence previously stated: The transistor is the building block for the computer hardware which makes up our system. correction: "The transistor is the building block for the computer hardware which makes up the integrated circuit."
- 4) Hackers fucked up the definition of socialism. page 35 in 3rd edition stated: "Socialism is the type of organization where the government funds the activity and also owns the productivity, or leaves it available as a public good. " correction: "Socialism is government ownership of the means of production."

repetition of the thesis of the book:

- 1) Swanson's law wrongly gives credit to Photo Voltaics industry for work done by other industries.
- 2) Subsidies to this industry were a waste.
- 3) Swanson's law could very well breakdown going forward.
- 4) This book has no opinion about the prospects of thin films solar.

B) Original Version, Unfunded



Excess costs incurred by premature solar photo voltaic build out:

The area under the curve below illustrates the leveled cost of energy differential between solar energy and combined cycles. Combined cycles are chosen here because they are an alternative to solar energy. The cost of energy curves are extrapolated based on estimates from wikipedia and Scientific American. The area in black stripes is the cost differential advantage of using combined cycles instead of solar photo voltaics.

It indicates out of the money nature of solar photo voltaic projects. These out of the money

projects were subsidized by government funds which would have been better placed elsewhere.

Instead of solar photo voltaic industry build out, those funds could have been better utilized on research and development or to enable combined cycle build out.

Citations:

## Images posted on IndieGoGo

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2) EE143 Solar Cells Fabrication Technologies, Lecture 26. Slide 14. From Sand to Silicon. Retrieved 201807326, from [www-](http://www-)

## **MARKET INEFFICIENCIES: AN UNMET NEED IN ACADEMIA**

### **NEED FOR Market Inefficiencies**

This book is proposed in order to expose inefficiencies within our economic system. It focuses on technology intensive industries.

The sample chapter available is SOLAR ENERGY: SWANSON'S LAW UNRAVELED. It has been rejected by academic journals. It exposes a flaw in the construction of the photo voltaic industry.

Structural bias within academic literature has a long only bias. This bias is evident in the title of the popular academic journal "Progress in PhotoVoltaics: Research Applications". As you can see from the title, the bias of the journal is in favor of casting the industry in a favorable light. But when authors expose the flaws in the industry, they are not receptive. Swanson's Law Unraveled was rejected for being outside the scope of Progress in Photo Voltaics.

The structural biases within industry literature contribute to bias in industrial decision. These can cause wrong decision in timing and choice of industrial build out. Current economic times are difficult for our nation's budget. In order to improve industrial decisions, its very important to get a clear image of the situation with all perspectives considered. Market Inefficiencies seeks to serve that need for a clear image of under-served perspectives.

The proposed book Market Inefficiencies will provide for arguments currently not served by academic literature. The chapter Solar Energy: Swanson's Law Unraveled will provide a for arguments not accepted by the establishment of the photo voltaic industry. Others chapters will follow suit if the situation merits.

The current summary chapter corrects the flawed logic behind the recent premature build out of solar infrastructure. Swanson's Law is a rule which relates the growth in photo voltaic industry to the drop in

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module prices. Originally named by the Economist, Swanson's Law draws a link between the Cumulative Module Shipments of photo voltaics to the decline in module price. This flawed logic formed the rationale which drove our government to subsidize the recent solar energy infrastructure build out. By correcting this misconception, better options for infrastructure planning can be achieved.

One chapter is available as a free preview. Only a small portion is available to summarize what the fully developed chapter is expected to look like.

**WRITTEN BY:**  
**JOSEPH MATTHEW WENDLAND**

## **BOOK SUMMARY**

There are huge inefficiencies in our economic system. These inefficiencies limit the ability of our economy to produce optimally. Current industry has some mechanisms to cope with market inefficiency. But these coping mechanism are lacking.

In this book I analyze various industries and show how the mechanisms of our system are inefficient. I also propose better methods to counter our system's inefficiencies.

Flaws in electric market limit its efficiency. Various coping mechanism exist to drive those inefficiencies.

**Sample Chapter:** Swanson's Law Unraveled is shown with a with a short five page summary. This is very brief. The completed chapter will discuss concepts in more detail and also show how substitution can better allocate those resources. The fully written book has a goal of achieving 300 pages.

### **Author Summary**

The author Joe Wendland faced rejection from the establishment for a related research paper: Swanson's Law Unraveled. Joe Wendland also writes a blog Yellow Dog News. Joe Wendland has a bachelor's degree in Chemical Engineering. Joe Wendland's work experience include in energy trading transactions in electricity and natural gas. Joe Wendland also did work as a software entrepreneur, a self-taught skill. Related companies: TA Technologies LLC, ATX Machine Services LLC, Yellow Dog News LLC, Yellow Dog Books LLC.

### **Book Outline**

1. Electricity Industry
2. Semiconductor industry
3. Intellectual Property

4. Operating System
5. Energy infrastructure transition
6. Drivers of growth decline: our generation vs their generation
7. Solar Energy: Swanson's Law Unraveled

1. Electricity Industry

- A. Carbon / environmental inefficiencies
- B. Pricing / taxing system
- C. Bonds of energy system
- D. A more efficient carbon tax
- E. Flawed green climate bond
- F. The ISO: a solution

2. Semiconductor industry

- A. The transistor explained
- B. Contributions to growth
- C. Leverage as applied to pricing.
- D. The effect on future resource allocation
- E. Questions and methods to separate and evaluate interconnected inventions
- F. Transfer pricing
- G. Value chain from transistor to final consumer
- H. Labor in the semiconductor industry. Mis-allocated due to IP system flaws.
- I. Freeloading off the transistor.
- J. Solutions to the inefficiencies

3. Intellectual Property

- A. Patents explained
- B. Copyrights explained
- C. Trade secrets explained
- D. Ideal case: how it should work
- E. Alleged flaws in IPs practice
- F. Viewpoints of market participants
- G. Bias of each market participant explained
- H. Ideas to improve intellectual property

4. Operating System

- A. Two extremes of pricing
- B. Each system's preferred user
- C. Effect of pricing on labor allocation

5. Energy infrastructure transition

- A. Wind and solar pricing points
- B. Transition phases
- C. Drivers of price reduction in pv
- D. Issues of grid connectibility
- E. Methods for future industry transitions.

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6. Drivers of growth decline: our generation vs their generation

- A. The freeloader effect real GDP growth vs real GDP
- B. Energy and carbon advances
- C. Change in environmentalism
- D. Trade policies affect on De-industrialization

7. Solar Energy: Swanson's Law Unraveled

Thesis: Swanson's law: a flawed relation: encouraged premature build out

- A. Introduction
- B. Flaws in Swanson's Law
- C. How those flaws mis allocate resources
- D. Better options given a correction to Swanson's Law

# **SOLAR ENERGY: SWANSON'S LAW UNRAVELED**

## **Chapter Summary**

### **1. Introduction**

The decades from 1990 to 2018 saw the expansion of solar cell infrastructure. During this time period, most solar projects were too costly to compete with conventional energy sources. In order to accelerate investment into out of the money solar infrastructure, state and national governments provided subsidies to these projects. These government projects and subsidies were driven by the logic of Swanson's law and the domestic infant industry argument. The flaws in these two arguments for government subsidies lead to a mis-allocation of scarce resources. A better understanding of these flawed arguments and their application can be used to improve future government policy and investment decisions.

### **2. Flaws in Swanson's Law**

Swanson's Law is a rule which relates the growth in photo voltaics industry to the drop in prices. Originally named by the Economist, Swanson's law draws a link between the Cumulative Module Shipments of photo voltaics to the decline in module price. Here it appears that increasing cumulative module shipments caused the decline in module shipments. The truth is that more causation for the decline in cost of photo voltaic modules can be attributed to sources outside the photo voltaic industry.

To find the real driver of cost reduction we must look into the solar module manufacturing process. An understanding of the manufacturing processes and their economic drivers will reveal the flaws in Swanson's Law. The manufacturing processes for high purity integrated circuit silicon and low purity photo voltaic silicon are linked. The photo voltaic quality silicon is secondary to the high purity silicon used for integrated circuits. The secondary status of photo voltaic quality silicon stems from its role in the process which purifies silicon. In this silicon manufacturing process, photo voltaic quality silicon originates from waste.

For the majority of their history, high purity silicon used for integrated circuits has been the

primary driver in the manufacturing process. Integrated circuit quality silicon has dominated the manufacturing process because of its much higher price. Integrated circuit quality silicon has also contributed more volume than its low quality counterpart for most of its history. The dominance in volume and prices of high purity silicon has caused the netback for integrated circuits to drive the improvements in the manufacturing process for most of its history.

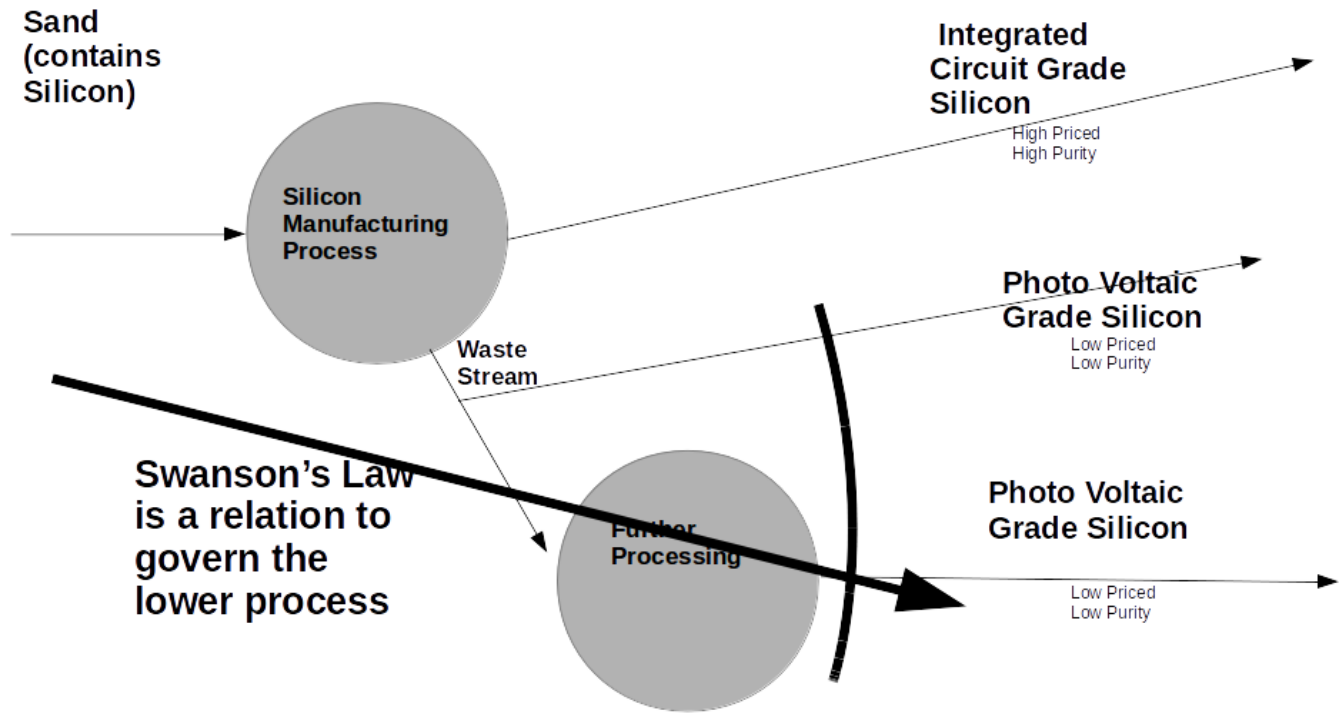
### 3. How those flaws mis allocate resources

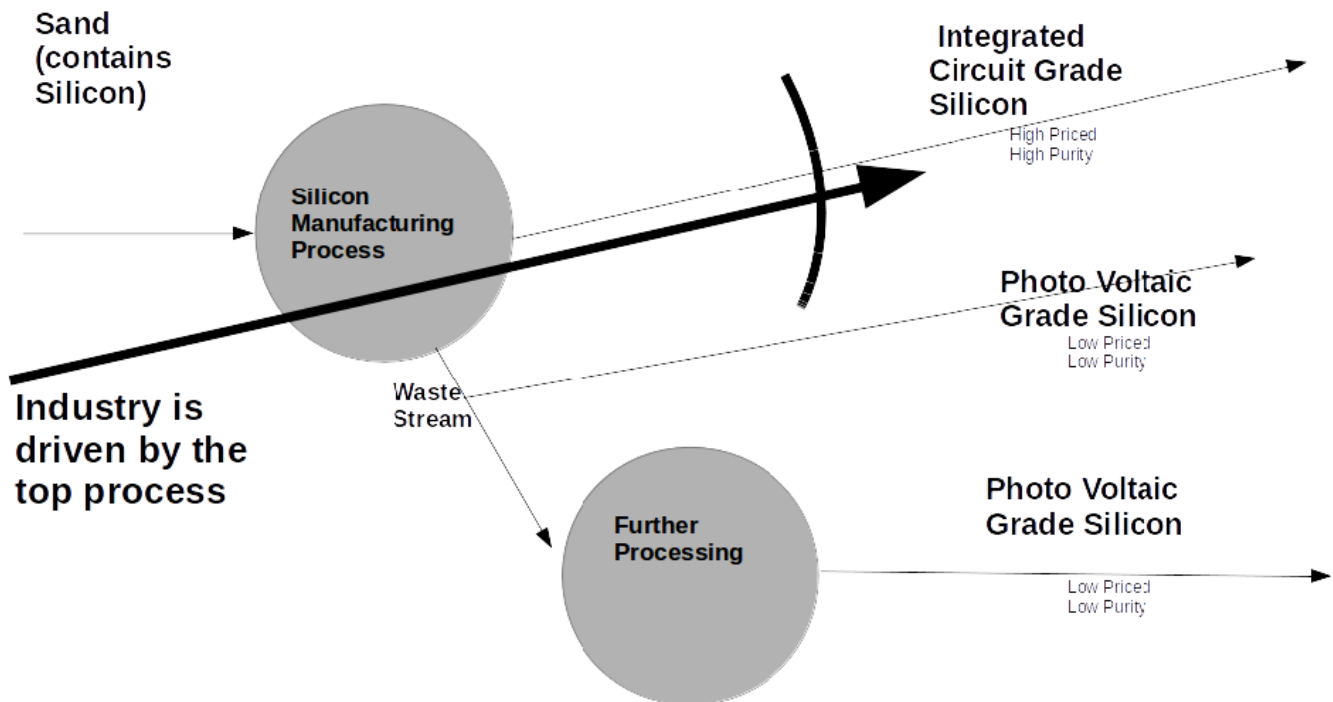
The flawed logic of Swanson's law caused the government to subsidize solar energy infrastructure. One example of these subsidies are the solar investment tax credit. According to SEIA, "As a result of the multi-year extension of the credit enacted in late-2015, solar prices have continued to fall while installation rates and technological efficiencies are continuing to climb. The ITC is nothing short of a tax policy success story and we expect this fact to continue to play out over the next several years," (4). The gains in technological efficiencies and the fall in solar prices can instead be attributed to the accomplishments of the integrated circuit industry. This flawed logic caused resources to be mis allocated from more valuable uses to photo voltaics. If that capital had instead been invested in other industries, it would provide better value for consumers.

### 4. Better options given a correction to Swanson's Law

A better option to the subsidies of solar infrastructure would have been to wait longer before the photo voltaic build-out. The past few decades of investments in solar industry should instead have been postponed. Even without the cumulative module shipments as shown by Swanson's Law, most of the declines in module price and technological efficiency would have occurred. As we approach the year 2020, photo voltaics are approaching cost competitive relative to conventional sources of energy. To delay solar infrastructure until subsidies are no longer needed would provide a better allocation of capital.

# Silicon Manufacturing Process





Comparison of IC and PV processes

- 1)  $V_{IC} \gg V_{PV}$
- 2)  $P_{IC} \gg P_{PV}$

Which leaves us with the process for integrated circuits as dominant process for silicon manufacturing. This holds for most of industries history. where:

- 1)  $V_{IC}$  is volume of silicon for integrated circuits
- 2)  $V_{PV}$  is volume of silicon for photo voltaics (solar cells)
- 3)  $P_{IC}$  is price of silicon for integrated circuits
- 4)  $P_{PV}$  is price of silicon for photo voltaics (solar cells)

When evaluating projects which rely on government subsidies for a domestic infant industry, such as photo voltaics, try to screen for this type of flaw. The flaw here is falsely attributing cost curves for the subject industry (photo voltaics) to an exterior and more influential industry (integrated circuits). Here the relation between joint products can explain the correlation. For Swanson's Law correlation does not mean causation.

In the chart below you can see the wedge of energy cost differential for different sources of energy. The combined cycle was chosen as a point of reference due to its low cost of energy and low carbon impact relative to the traditional conventional sources of energy. The combined cycle is the grey component below the solar area, from 0 to 73. The wedge in black stripes represents the cost premium for solar energy relative to a combined cycle alternative.

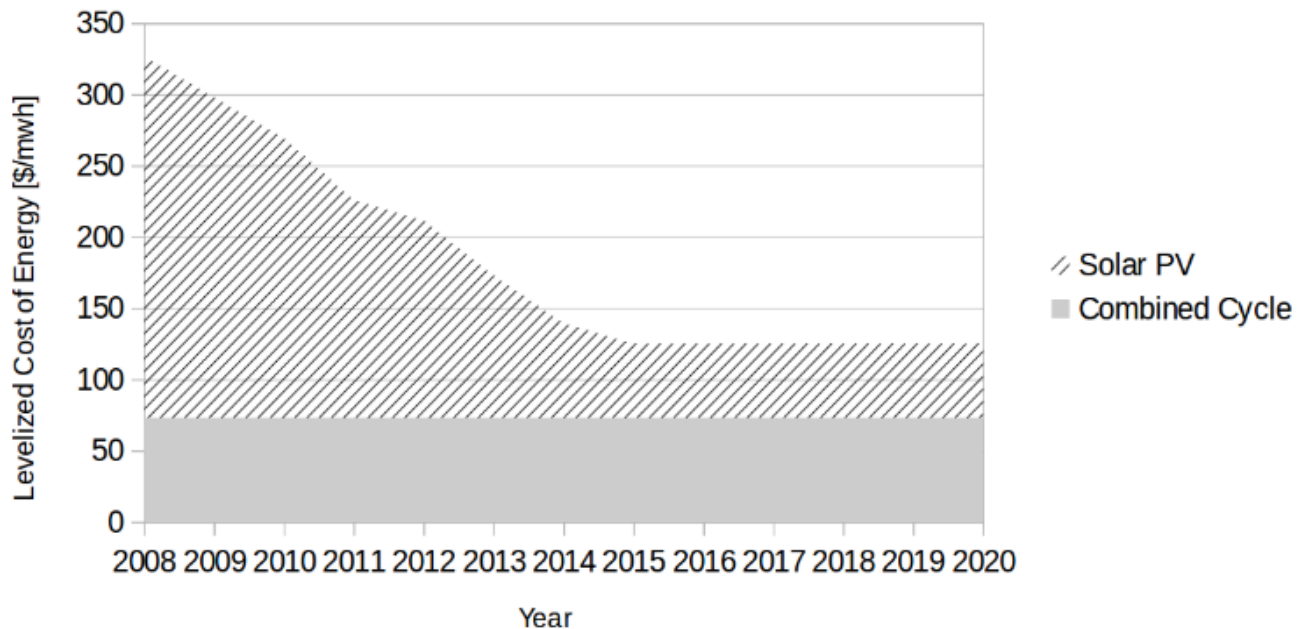
As you can see from the chart below, the cost differential narrows over time. This reflects the gains in technological efficiency in solar energy as time progressed. According to the logic of subsidies and the domestic infant industry argument, the additional costs shown in black stripes will one day pay back.

The newly exposed flaw in Swanson's Law means that industry did not need to incur the losses in black stripes to get the benefits of solar some time during the 2020s. Instead of the losing solar investments shown in the black stripes section of the chart, industry should have postponed solar

investments. It would have been more economical for the solar industry to freeloading off the integrated circuit industry during the period 1990 to 2018.

Excess costs incurred by premature solar photo voltaic build out:

### Energy Technology Comparison



The area under the curve below illustrates the leveled cost of energy differential between solar energy and combined cycles. Combined cycles are chosen here because they are an alternative to solar energy. The cost of energy curves are extrapolated based on estimates from wikipedia and Scientific American. The area in black stripes is the cost differential advantage of using combined cycles instead of solar photo voltaics.

It indicates out of the money nature of solar photo voltaic projects. These out of the money projects were subsidized by government funds which would have been better placed elsewhere. Instead of solar photo voltaic industry build out, those funds could have been better utilized on research and development or to enable combined cycle build out.

Citations:

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